Object storage

Kurz, Sirpa ; Freiag, Anne ; Nyffeler, Reto ; Scheyer, Torsten ; Troxler, Martin ; Hotz, Benedict ; Stauffer, Fred ; Neisskenwirth, Fabian ; Neubert, Eike ; Mazenauer, Janine ; Greeff, Michael ; Baur, Hannes ; Liersch, Stephan ; Vilhelmsen, Lars ; Litmann, Jessica ; Cibois, Alice ; Hofmann, Beda ; Price, Michelle ; Frick, Holger

DOI: https://doi.org/10.5281/zenodo.4316839

Originally published at:
Kurz, Sirpa; Freiag, Anne; Nyffeler, Reto; Scheyer, Torsten; Troxler, Martin; Hotz, Benedict; Stauffer, Fred; Neisskenwirth, Fabian; Neubert, Eike; Mazenauer, Janine; Greeff, Michael; Baur, Hannes; Liersch, Stephan; Vilhelmsen, Lars; Litmann, Jessica; Cibois, Alice; Hofmann, Beda; Price, Michelle; Frick, Holger (2021). Object storage. In: Frick, Holger; Greeff, Michael. Handbook on natural history collections management : A collaborative Swiss perspective. Bern: Akademien der Wissenschaften Schweiz, 33-85.
DOI: https://doi.org/10.5281/zenodo.4316839

Vol. 16, No. 2, 2021

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Handbook on natural history collections management

A collaborative Swiss perspective

Chapter 2: Object storage

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2.1 Introduction

For centuries, natural history collections have preserved snapshots of objets from past and present environments, forming an established foundation for analysing biodiversity and geological diversity information, something that can be used when addressing and solving issues for the future. Concurrent with the industrial revolution and massive human interference with the natural world, natural history collections have been documenting the stages of a rapid and irrevocably changing world. Collection facilities themselves have also been subject to constant transition as advances in science and technology lead to novel preservation methods and changing collection priorities, forever transforming our perspectives on natural history specimens. For instance, naturalists assiduously assembled organisms from all continents for the past 250 years to study their morphology and anatomy. The very same specimens now allow researchers to investigate the evolution of insecticide resistance or the genetic variation of species through time and space using modern methods of molecular biology (Wandeler et al. 2007, Harmon et al. 2019).

Natural history collections therefore face the challenge of conserving material samples, without knowing what they may be used for in the future (Keene 2005). Collections should thus aim to maintain specimen integrity for as long as possible. These days, this includes not only the shape, colouration and general appearance of a specimen but also its chemical composants, genetic material, associated parasites, environmental pollutants, dust and pollen grains, injuries and many other attributes. Accordingly, collection curators need expertise in a wide spectrum of available conservation methods and access to on-going training to faciliate informed decisions. Conservation methods have been extensively documented and some key references are listed later in this chapter. In addition, international associations such as the Society for the Preservation of Natural History Collections (SPNHC) publish Best Practice guidelines, organise meetings and internet forums for collections staff to interact with experts as well as to exchange knowledge among stakeholders. The Consortium of European Taxonomic Facilities (CETAF) also runs a specific Collections Group that unites European collections managers to discuss emerging topics and work on collections management or curation based issues. Given these excellent resources, the chapter at hand does not intend to be another standard work in collections preservation. It rather provides an instrument for efficiently identifying the most urgent shortcomings in the preservation strategies of natural history collections and, as a result, to rescue collection holdings in imminent danger of loss or lasting damage.

Further reading

- for a general overview on natural history collections, see Carter and Walker (1999) or more recently Elkin and Norris (2019)
- for the storage of botanical specimens, see Bridson and Forman (2000)
- for the storage of geological objects, see Brunton et al. (1985) or more recently, Stanley (2004)
- for a Swiss reference and contact for storage facilities, see Huber and von Lerber (2003)
- for a detailed, up to date online compendium on collection curation, see NPS (2020) and some of its appendices NPS (2005a, 2005b, 2019)
- to get dynamic and up to date online information on best practices of collection curation and storage, visit SPNHC (2020a) and STASHc (2020), respectively

Figure 2.1.a: Insect drawers at the ETHZ-ENT in Zürich (photo ETHZ-BIB / Pierre Kellenberger)

2.2 Buildings

When building or renovating collection facilities, many conflicts of interest arise, most frequently in the trade-off between optimal storage versus optimal working conditions. Sealing the collection off from external influences (i.e. no windows, just one door) and controlling conditions is best for collection holdings (see section 3.2), as the risk of physical damage to objects and entrance of pests is minimised. These conditions, however, are often unpleasant or unhealthy for the workforce while being in conflict with employment laws. Furthermore, proximity of the collection to the rest of the institution will influence working comfort and the possibility for enabling collection visits by the public. Available space and technical constraints of the building should also be taken into account. Finally, doors and elevators must be big enough to allow the transport of even the largest collection units.

Storage facilities built in existing museum or herbarium buildings often have the advantage of being favourably situated and in close proximity to the rest of the institution but may imply trade-offs with regard to space and technical infrastructure. In contrast, the construction of a new collection facility may assure optimal storage conditions but have the disadvantage of being far away from the rest of the institution.

Recommendations

→ place working facilities close to the collection but not inside it

→ for the planning of new storage facilities, contact specialised companies such as PrevArt GmbH (Winterthur CH, www.prevart.ch)

Examples

- a new collection building for wet and entomological collections is planned by the MHNG in Geneva. It will be connected to the existing buildings, have a single main entrance, emergency exits and no openable windows. Three rooms at room temperature and with natural light allow for on-site examination of specimens. All offices of the scientific staff remain in the original buildings
- a former storage facility, offering separate, temperature-controlled rooms for herbarium sheets and collections staff, is used by the collections of the MNVS in Sion. The offices for administration and researchers, and for the exhibition are in town
- partly housed in the museum building in town and partly in a depot 30 km outside of the city are the collections of the MZL in Lausanne. As they are the most used and require the least space, the entomological collections remain in the museum, whereas other invertebrates and the vertebrates are stored in the depot

2.2.1 Weight carrying capacity of floors

The weight loads placed on the floors should take into account the number and height of the movable compactor system planned for any given surface as well as the estimated weight of the collections. When choosing a system, the carrying capacity of the floors should be kept in mind as the average load of a movable compactor systems is almost double compared to fixed racks due to the absence of aisles between shelving units.

In new or renovated facilities, collection growth may eventually fill all empty space on the shelves and impact original carrying capacity calculations. Transit of further materials through the facility (e.g. basic material to mount, prepared or disinfested specimens, new acquisitions) should also be taken into consideration when calculating the total weight of a given collection.

Exceptionally heavy collections

Geological and palaeontological collections are heavy and floors must be able to bear their collective weight (see figure 2.2.1.a). This can be taken into account when building new facilities but may be a limiting factor in older buildings.

Wet collections exist in different collection facilities and can also be heavy, especially if glass jars (and glass vials within the glass jars) are used. Botanical collections may be heavy due to the specimen sheets, folders and cardboard supports used to store the specimens. The maximum load will be reached more quickly in herbaceous families with very thin specimens as a typical pile will contain many more specimens than that of a woody family and, as a consequence, the combined weight of the paper materials will be much higher.

Figure 2.2.1.a: Very heavy palaeontological collection from the Monte San Giorgio at the PIM in Zürich (photo Torsten Scheyer)

2.2.2 Rooms

Housing collections in basements should be avoided because of dampness and the risk of flooding. In most cases this is associated with automatic sprinklers, runoff as a result of fire-fighting activities, floor drains or even lab safety showers, but it can also be due to high ground water levels. In cases where climate control is necessary, new air conditioning units require thorough testing before being put into operation followed by regular monitoring and maintenance, especially during extreme weather conditions. Furthermore, storing similar materials together will facilitate cost effective application of the most appropriate environmental conditions for all materials (Museums and Galleries Commission 1992).

Ideally, collections storage areas should not have windows. If present, they should be blacked out to protect objects from external UV light and covered by mesh to prevent the entry of birds and insects (Carter and Walker 1999). The height of the room will determine the height of the movable compactor system and therefore the overall storage capacity of a collection. Several major European museums and herbaria have tall compactor systems and the uppermost shelves are accessed by mobile ladders. In this case, the risk of falling, for both staff and the materials, should be kept in mind. A minimum of 50 cm should be kept between the top of the compactor system and the ceiling, so air circulates, dust can be easily vacuumed and the lighting system can be maintained.

Recommendations

- → test and monitor new air conditioning units thoroughly
- → store similar materials together
- → protect rooms from external UV light and pest organisms by using appropriate windows and window covers
- → storage rooms should be as water and fire proof as possible, and free of dust

Examples

- a new air conditioning system in a new storage facility did not fully comply with the required conditions for the room and had to be refurbished, at great expense, in the NML in Luzern in 2017 (for details, see Hotz 2018)
- although theoretically underground rooms better regulate large fluctuations in humidity and temperature throughout the year, control of these parameters remains complex and they are permanently monitored in the herbaria of the CJBG in Geneva

2.3 Considerations for shelving systems

Shelving systems are available in all shapes and types. Finding the right one depends on facility parameters like space, the carrying capacity of the floors and the needs of the collection. Here we discuss shelving types and their arrangements, while practical applications for specific types of collections and groups of objects are discussed in the sections 2.5 to 2.8.

2.3.1 Types of shelves

Different considerations are needed before deciding on a type of shelving system that fits the needs of stored specimens. Some specimens are sensitive to evaporation, others to vibrations, insufficient air circulation or dust. Still others may be particularly heavy or need to be stored in special compartments, like those that can be placed in drawers. Solutions that address different needs are discussed here.

Wood versus metal

Independent of the type is the choice of materials. In general, shelves should be made of chemically inert materials (non-reactive and that do not emit gases), such as steel. If necessary, they can be covered with closed-cell polyethylene foam in order to protect artefacts from contact with the metal.

Metal cabinets are therefore the preferred choice for most materials and are in use in most modern collections. They have the advantage of being cheap, as well as easily produced and adapted to the needs of a collection. They are durable and easy to clean, which can be important in pest insect detection and pest decontamination (see section 3.4.2).

Wooden racks were used traditionally and are still in use nowadays. Wooden cabinets can efficiently buffer fluctuations in temperature and relative humidity but are suboptimal in case of fire. In addition, most woods (particularly oak) are known to emit organic acid fumes to which some biological materials like bird eggs and mollusc shells are sensitive. Evaporating acids can also cause metal pin corrosion in insect collections (Carter and Walker 1999).

Fixed racks versus movable compactor systems

Movable compactor systems have been used in natural history collections since the 1970's and their use has become a rule in order to optimise the physical space available to house scientific collections (see figure 2.3.1.a). Although they save space, the vibrations caused by opening and closing the compactor system can cause mechanical damage to the stored specimens, especially if the collection is in heavy use (Carter and Walker 1999).

Nowadays, movable rack systems are also available with electric engines. They move more smoothly than the manual ones but cause more vibrations and require electricity, which may be an issue for certain types of objects e.g. those stored in wet collections. Both have their advantages/disadvantages and the choice of system should suit the needs of the stored collection items.

Open versus closed shelves

There is a trade-off between good ventilation and protection from dust. The risk to objects posed by dust is gen-

Figure 2.3.1.a: Manual movable compactor system installed in 2011 to house plant specimens in the CJBG in Geneva (photo CJBG)

erally considered to be lower than the damage caused by potential mould outbreaks resulting from insufficient ventilation. Ideally, air can be filtered by the ventilation system so that dust is reduced to a minimum.

By keeping enough space between the specimens, air circulation can also be optimised inside closed shelving systems, including movable compactor systems. The space should be large enough so that every specimen may be removed without moving other specimens, thereby reducing the chances of mechanical damage.

Besides the protection that closed cabinets provide against dust, well-designed systems may also prevent pest insects from entering and attacking stored specimens. If dust is a major issue in a collection facility, open shelves can also be protected by dustproof covers (Carter and Walker 1999).

Racks for large and/or heavy specimens

Racks are commonly used for large and/or heavy specimens like vertebrates and rocks (see figure 2.3.1.b). Since the size range of such objects can vary considerably, a system that can be adjusted to accommodate differently sized objects is highly recommended.

Heavy objects also include rocks or liquid jars that are too heavy or risky to be lifted, held or moved by one person alone. Such objects are ideally stored in places where they will be moved as little as possible. For this reason, they are usually kept separate from the rest of the items in the collection.

Heavy rocks are best stored on fixed, non-mobile shelves of a rack (e.g. heavy-duty shelving). Larger, heavier stones with an individual weight of up to 60 kg can be stored in plastic or wooden stacking boxes on shelves with a load capacity up to 130 kg. Plastic stacking boxes are available in different heights and sizes in so-called Euro-Dimension, adapted to euro-pallets (120 × 80 cm). Although the stacking boxes make it easier to handle the heavy stones, a pallet truck or forklift is required for lifting them due to their overall weight. The stacking containers also do not protect against tipping when pulled out of the rack.

If there is sufficient space, heavy objects can also be stored on a mobile surface that is easy to move and manoeuvre (e.g. euro-pallet or wooden plate with rollers).

Drawers and compartments

Smaller items usually need special protection and are therefore stored in drawers with compartments. For example, rocks, fossils and minerals can be placed in ac-

Figure 2.3.1.b: Adjustable racks for large specimens in the NSFL in Triesen (Photo Holger Frick)

Figure 2.3.1.c: Wooden drawer with cardboard compartments for malachite samples in the geological collection of the NMBE in Bern (photo Lisa Schäublin)

id-free cardboard boxes in wooden or metal drawers of different dimensions (see figure 2.3.1.c). Delicate items such as eggs or shells are usually stored in covered compartments, but see sections 2.7 to 2.8 for specific details on the internal division of drawers. Drawers can be used in combination with shelves or may be integrated into movable compactor systems. There are standard drawers on the market with a load capacity of up to 60 kg. Drawers have the advantage that they usually run in a guide rail and therefore cannot tip over when pulled out. Since not all samples are of the same height, there are various options for arranging drawers in a cabinet. They can be arranged at a regular distance from one another that is adapted to the average height of the objects. In this way, the drawer arrangement is easy to plan but cannot accommodate larger than average pieces. A height-adjustable arrangement of the drawers enables different distances and objects of different heights to be stored in the drawers. However, the entire arrangement must be adjusted, sometimes with great difficulty, if a larger piece is to be accommodated after the division of the drawers.

Insect drawers

A special system is required to store insects, since the storage drawer/box is independent of the shelves. Different systems are available from different companies. For entomological collections, shelves are often custom-built according to the size of the entomological drawers. This can be a disadvantage if the drawer size is changed or if the supplier changes the model.

The shelves must be wide enough to accommodate most drawer sizes. The drawer lenghts range from 30–51 cm, to over 70 cm in historic collections. Ideally all drawers are of the same size. This avoids problems, e.g. if drawers have to be moved or shifted from one shelf to another.

Keep in mind that the height of the drawers may also be variable. Drawers of modern collections are usually 6 cm high but they are sometimes higher in historic collections or in drawers specially designed to accommodate large specimens. Some space between the drawers is also helpful to facilitate access, despite the loss of storage space associated with such spacing. Modern metal shelving has L-shaped elements on which the drawers are placed. If the drawers are too narrow to be placed on these, a thin board made of acid-free material can be used to support them.

Figure 2.3.1.d: Integrating specimens that are too large for unit trays (as seen in figure 2.7.2.a) in an insect drawer with thin line compartments in the MHNF in Fribourg (photo Michael Maillard)

Recommendations

- → use metal cabinets and racks rather than wooden ones
- → use movable rack systems for collections that are not frequently used or to store specimens that are insensitive to vibrations
- → make sure that air circulation is sufficient (also in closed racks) by keeping space between the specimens or storage units, and raising cabinets on plinths
- → protect specimens from dust using filtered ventilation or some other type of dust protection (dust covers) in storage environments with no ventilation system
- → use wooden or metal drawers with guide rails
- → use stacking boxes made of wood or plastic for large and heavy objects (up to approx. 60 kg) and place them on stable shelves
- → restrict the variety of drawers and compartments to a few standard sizes

Examples

- to avoid vibration, LAU in Lausanne replaced the electrical compactor systems by completely mechanical systems
- for economic reasons the Sammlungszentrum des Schweizerisches Nationalmuseum and the NML in Luzern use manual movable compactor systems
- metal shelves are in use in most natural history collections e.g. at the MZL in Lausanne, the NMSG in St.Gallen, ETHZ-ENT in Zürich or CJBG in Geneva
- wooden shelves are in use in the NSFL in Triesen
- for storing smaller stones, wooden drawers with guide rails are used in the movable compactor systems of the NML in Luzern. Heavy pieces are stored in plastic stacking boxes on stable shelves

Suppliers

- movable compactor systems are made by Bruynzeels Storage Systems (Frauenfeld CH, www.bruynzeel.ch), Kompatech GmbH (Regensdorf CH, www.kompatech.ch/rollregale) or Forster Archiv- und Verkehrstechnik GmbH (Oetwil am See CH, www.forster-archiv.ch)
- drawer systems are made by Bruynzeel Storage Systems
- heavy-duty shelves are made by Läderach Lagersysteme AG (Langenthal CH, www.laederach-lagersysteme.ch)
- find RAKO-boxes at Georg Utz AG (Bremgarten CH, www.utzgroup.ch)
- get FOREG rack systems including those of high load capacity from Forster Archiv- und Verkehrstechnik GmbH

- Entomologie Meier (München DE, www.ento-meier.de), Tischlerei Dieter Schunke Entomologische Erzeugnisse (Wolferstedt DE, https://shop.schunke-tischlerei.de) and Paradox Company Dariusz Skibiński (Krakau PL, www.insectnet.eu) supply insect drawers and cabinets
- special shelving systems for larger collections are made by Lista AG (Erlen CH, www.lista.com)

Further reading

- for a discussion of all types of shelving system see Carter and Walker (1999)

2.3.2 Arranging specimens and shelves

Stored objects should be found easily by all users, not only experts. Specimens should therefore be stored systematically, taking into consideration the extra space that must be reserved for new acquisitions. In other words, specimens of the same species or type of rock are next to each other and are organised systematically, for example, by genus, family, order and class, or their equivalents in geosciences. Within a systematic rank organisation system, an alphabetical rather than phylogenetic arrangement is usually more practical, given that no phylogenetic knowledge is needed to find a certain specimen. To facilitate retrieval, it is recommended to give a reference to the publication, classification or online reference (with date of retrieval), that has been used as basis for the systematic arrangement of the collections as well as the naming standard(s) used.

However, this approach has the disadvantage that approximately 20% of the space has to be kept empty (often the upper and/or lower racks, drawers etc. of a shelf) for future acquisitions. But it is still preferred over the space saving but more 'chaotic storing systems' (no order, location only given in database) that are highly dependent on correct data on the storage place of an object, and a dependable retrieval system. The risk that an object is lost due to erroneous location data or due to a mistaken placement is high.

Correspondingly, the arrangement of the shelves and its sections should follow the placement system used in libraries for hundreds of years. Following the chosen organisation system, start on the highest rack, continue down (while leaving out spaces, especially if acquisitions are likely) and repeat on the section to the right until the end of the row. Start a new row on the shelf opposite, from the last object of the last row, at the top of the shelf. Rows should be arranged from left to right.

Recommendation

→ arrange specimens according to a documented and methodical system from top-down and left to right, leaving empty space throughout for acquisitions

2.4 Labelling objects

Connecting objects and information is fundamental for the efficient management and use of a scientific collection. This section details the information that should be on a specimen label, the label material itself and how the label should be attached to the object. Specific information unique to certain types of specimens, like those stored in fluids, pinned insects, cryptogams stored in packets, fungi stored in boxes and fossils are given in their respective sections.

Label information

Labels should include some minimum amount of data on the collection event (date, location, collector(s), collection number) and the identification of the specimen. The more information that is physically connected with the object via a label, the better (see figure 2.4.a). The data should also be made available digitally (see chapter 4). It is important that the verbatim data on the labels are connected to the specimen in the databases, e.g. by using unique identifiers like unique catalogue numbers or barcodes, and also that verbatim and interpreted data are partitioned in the database (see section 4.7.3). Since the scientific value of a specimen depends as much on the original label data as on the specimen itself, it is essential that a label is never separated from its corresponding specimen.

There are three kinds of information that may be found on one or more labels (Carter and Walker 1999). The most important label is the 'locality label', which gives basic collecting data: country, town, field name, co-ordinates, altitude, followed by the date and the collector(s), with a collection number.

The 'identification label' gives the species name, the name of the person that identified the specimen and the date of identification. Never remove these labels as they are an original source of data. If information from the original labels is transferred to new labels that are more easily read, these new labels are considered to be an interpretation of the original data and should never replace the original label. If label information is annotated, corrected or approved by an authority, this information should be given on an additional separate label.

Figure 2.4.a: Labelling a pinned insect in the NMBE in Bern (photo Lisa Schäublin). Top cardboard with genital preparation, with locality label below and an identification label at the bottom

In theory, the verbatim, or original, label places a specimen in its historical context in time and space and is thus essentially important, especially if the specimen in question has been referred to in the scientific literature and may thus be used to check interpretations of abbreviations or handwriting on the basis of the information taken directly from the original labels. Often the original handwriting is the one of the vital clues to the origin of an important specimen and can be key for tracing types (Carter and Walker 1999).

'Curatorial labels' or annotation labels show accession details such as the GBIF-CH codes or other codes, unique catalogue

Figure 2.4.a: Labelling larger objects with acid-free paper labels attached using string in the MHNG in Geneva (photo Philippe Wagneur)

numbers, the type status or designation, new taxonomic determinations. Labels that have accumulated over time should be arranged following the age of the label. New labels should be added in a way so that manipulation of the existing labels is kept at a minimum. Ideally, the catalogue number or barcode is visible without manipulation of other labels.

Label material

In general, labels should be made of acid-free material with a pH of 6.5 to 7. Ideally, acid-free long fibered 100% white cotton rag paper of a minimum paper weight of 100 g/m² should be used for both dry and wet collection labels (Carter and Walker 1999, NPS 2012). Information may be handwritten using carbon-based inks with a neutral pH (NPS 2005c), like China Ink. Such ink can be applied with technical pens, such as Rapidiographs, or other types of pens that contain appropriate conservation grade ink. Due to experience with historical samples, it is known that this type of printing can last on labels for several hundred years. Although some printers use similar carbon-based inks, the longevity of machine-printed labels (including laser printers) has yet to be determined, given their relatively recent emergence. It is therefore recommended to, at least, write the catalogue number of the specimen by hand. For special recommendations concerning wet collections, see section 2.5.

How and where to attach labels

Depending on the type of object, labels can be placed directly on the specimen (like catalogue numbers on bones or rocks), attached to label or the same surface on which the specimen is mounted (in the case of herbarium sheets), attached to the specimen (labels in vertebrates) or attached to the packet or jar containing the object (see figure 2.4.a). Since this information is very collection-specific, details are given in section 2.5 for wet collections, section 2.6 for herbaria, section 2.7 for zoological specimens, section 2.8 for geoscientific samples and section 2.9.1 for microslides.

In any case, labels should be made of acid-free, unbuffered materials, especially for those labels that are in contact with the preserved specimens or the liquids they are preserved in. Primary type (holotype) specimens are often marked with an extra red label to make their retrieval from collections easier, however, this is problematic in wet collections.

The special case of partially labelled series

In some cases, locality and identification labels are not found on the individual specimens themselves but rather pinned at the beginning of a series of specimens, either affixed only to the first specimen or simply pinned in the drawer at the beginning of the series. In such cases, the curator must make the very difficult decision of deciding whether it makes sense to associate this single label with

all of the specimens in the series. If so, a photocopy of this label may be affixed to each specimen, along with an additional label explicitly stating the uncertain nature of the association between specimen and label. In such cases, a high-resolution photograph of the original drawer, showing the specimens and the labels contained in the box, should be taken before any specimens are moved from the drawer for relabelling or displacement into another box. The photograph may be used for consultation purposes and as a control to make sure specimens remain associated with their original series.

Recommendations

- → give minimum label information like location, date, collector, determination and a reference to additional information via a catalogue number or barcode
- → always keep the original label with the object to preserve the verbatim label information
- → use pure carbon inks, like China Ink, for labels
- → use acid-free, unbuffered paper of pH min 7.5, with reserve 2% calcium carbonate made of 100% pure and new cellulose of min. 100 g/m^2 weight for labels, i.e. of archival standard (ISO 9706 warranty)
- → use colour coding of labels of type specimens to make their retrieval from collections easier (not in wet collections). Red is widely used for primary types, and in some cases, also for secondary types
- → establish an archive of historical label handwriting for reference purposes, either in the collections or ideally in a central public database

Examples

- for labels CentoPro ultraweiss (100, 120, 140 und 160 g/m^2), for index cards SKY®PREMIUM 200 g/m^2 and for different archival purposes Museumspapier Qualität 12, is used at the NMB in Basel
- for herbarium labels, Normaset Puro (Bio Top 3), 160 or 200 g/m^2, ISO 9706 is used by the Herbarien Basel
- for archival purposes, the NMB in Basel uses transparent protective sleeves made of polyester and protection bags made of Pergamin

Suppliers

- for label paper, see specialised stationary stores or Oekopack Conservus AG (Spiez CH, www.oekopack.ch), Antalis AG (Lupfig CH, www.antalis.com)
- for index card paper, see Papyrus Schweiz AG (Thalwil CH, www.papyrus.com))
- for self-adhesive labels, see Oekopack Conservus AG or OPAL Associates AG (Wetzikon CH, www.opal.ch)
- for acid-free adhesives, see CTS Europe (Altavilla Vicentina IT, www.ctseurope.com/en/catalogo.php), Lascaux (Brüttisellen CH, https://lascaux.ch), Zumstein (Zürich CH, www.zumstein.ch), or Klug Conservation (Immenstadt DE, www.klug-conservation.de/Klebstoffe-Tylose-MH300)
- for transparent protective sleeves/bags, see Oekopack Conservus AG or Atlantis France (Noisy-le-Grand FR, www.atlantis-france.com)
- for a list of suppliers, see Petrak (2016)

Further reading

- for labelling material, see NPS (2005c, 2012)

2.5 Wet collections

In wet collections, as in all other collections, only acid-free and unbuffered materials should be used. This is especially important for glass jars, as well as for the labels that are stored together with the specimens inside the preservation liquids. For general information on the content of labels and label materials, see section 2.4. The placement of labels is discussed here. Information on storage materials and compartments follow in the subsequent sections.

Invertebrates, vertebrates and plants preserved in liquids
Mainly soft bodied invertebrates are preserved in liquids (see figure 2.5.a). These can be insects, spiders, molluscs and many other marine invertebrates. Small specimens are usually kept in vials that are stored together in jars full of the preservation liquid (see section 2.5.4). Soft bodied specimens are preserved well in liquids.

In the special case of malacology, preserving the soft body parts give an added value to the main specimen (hard shell). Here, the soft body together with the shell is stored rather than just the shell in the dry collection. Thick shells can be stored in ethanol for a very long time without any negative effects. In thin-shelled species, the animals should be immediately separated from their shells; the body should be stored in alcohol and the shell integrated into the dry collection.

Vertebrate specimens like small mammals, fish, amphibians and reptiles can be stored wet. Even very large specimens like whole sharks can be stored in glass cylinders or tanks. Historically, this preservation method has also been used for various, usually bulky, botanical samples such as seeds, flowers or flower heads.

The preparation of insects for liquid preservation
Most very small to small insects can be killed directly in the preservation liquid. However, if the specimen is needed with relaxed muscles for preparation and handling, they should be dazed and killed with ethyl acetate or cyanide. Afterwards, make a short longitudinal incision in the inter-segmental skin of the abdomen and place

Figure 2.5.a: Modern invertebrate wet collection of the MHNG in Geneva (photo Philippe Wagneur)

Figure 2.5.b: Vertebrate wet collection combining restored historical glass jars and modern glass jars with twist-off lids in the NMBE in Bern (photo Lisa Schäublin). Specimen information is given on labels inside the jar. The extra label on the lid contains storage location information, only.

specimens in Pampel's Fixative (30 ml 95% ethanol, 10 ml 35–40% formaldehyde, 2 ml glacial acetic acid, 60 ml water) for 2–6 hours. Then place specimens in a container with 60% ethanol and leave it open for 24 hours in a well-ventilated place. It is important that the specimens do not dry out. Specimens may then be transferred to suitable glass tubes containing 75% ethanol. Tubes should be closed with cotton wool and placed in a suitable jar filled with 75% ethanol.

Labels in liquids

The materials and methods for labelling jars in wet collections follow the same rules as for other labels (see section 2.4) or for labelling vials inside a jar (see section 2.5.3). The paper must be of archiving quality, acid-free, unbuffered and of approximately 120g/m² weight. The protective buffer in many archiving papers may cause changes to the pH value of the liquid, which could have a negative impact on the sample. The labels inside the jars must be made of paper that can withstand long-term immersion in liquid without softening or becoming discoloured (Carter and Walker 1999).

If a jar includes only one specimen, it must contain all the necessary information about the specimen itself (see section 2.4). If a jar contains several vials, each containing specimens with different labels, the type of information on the labels will vary, correspondingly. In this case, the jar label should carry the information common to all the vials it contains. Usually this is the most common taxonomic rank (i.e. order, family, genus, species and its author). The application of a jar number makes it easier to find the samples. It is important that at least the catalogue number is written on the label by hand with China Ink (India ink, supplied with carbon-particulates) due to its proven longevity. The information on specimen labels can be applied with carbon-based inks (either by hand or corresponding printers) or laser printers. However, keep in mind that the longevity of machine-printed labels has yet to be determined (see section 2.4).

Always label the sample and the jar. If labels are to be attached to specimens using string, make sure that the string is also of archival quality. It is recommended to use pure cotton twines. The string must not be stained under any circumstances, as the colour dissolves in ethanol, which leads to undesired colouring of the liquid or the preparations. For external labelling of jars, age-resistant labels with dextrin gum coating are used. These labels adhere very well to glass.

Storing the wet collection

If using a movable compactor system, it must be moved carefully so that the jars and their contents are not shaken too much. There should be a raised edge at the front of the shelf to prevent the jars from falling (see figure 2.5.c). In addition to stabilising edges and struts to steady larger jars, a drip tray for any leaked conservation liquid is a

requirement in many places and is highly recommended (Carter and Walker 1999). If there is no movable compactor system, use heavy-duty metal shelves. The surfaces should be smooth and easy to clean.

Trays and compartments to group jars

If there is a desire to group jars and store them in system containers (e.g. RAKO), one must keep in mind that jars filled with liquid are heavy. The more jars in a container, the heavier it is. This does not make transport easy and damage may occur if jars slide while being moved. Jars should be moved as little as possible to reduce disturbance of their contents. In order to keep a clear overview, the trays can be divided with strips and if necessary, the trays can be labelled.

Recommendations

- → label jars and specimens with age-resistant material
- → mark jars and containers on the outside and the inside
- → use un-dyed cotton string for object labelling, especially if several objects in the same container need labels
- → use extra jar numbers to find the samples more quickly in larger collections. These can be attached to the lid to reduce disturbances when searching for a jar

Examples

- for a detailed set of practical recommendations to restore and to build up a wet collection based on the experiences at the Naturkundemuseum Berlin and others, see Neuhaus et al. (2012)
- for an up-to-date refurbished historical wet collection, see the 'Steinmann Collection' of the NMBE in Bern
- the MZL in Lausanne uses acid-free paper of 100 – 120 g/m^2 printed using a laser printer
- an archival high quality paper that is suitable for wet collections (Pretex 'copy + laser' paper) of 90 and 120 g/m^2 weight is used by the NMB in Basel
- for information on modern wet collections and storage conditions, contact the MHNG in Geneva, that is currently constructing a new collection building solely for wet and entomological collections

Figure 2.5.c: Metal drawers with raised edges for the jars of the wet spider collection in Naturalis Biodiversity Center in Leiden (photo Holger Frick)

Suppliers

- get Resistall-paper from Preservation Equipment Ltd (Norfolk UK, www.preservationequipment.com)
- get label paper from Klug Conservation (Immenstadt DE, www.klug-conservation.de/Etikettenpapier-Etikettenpapier) or Oekopack Conservus AG (Spiez CH, www.oekopack.ch/produkte/spezialitaeten-zubehoer.html#-etikettenpapier)
- get Pretex paper from Papyrus Schweiz AG (Thalwil CH, www.papyrus.com) or FiberMark (Lahnstein DE, www.lahnpaper.de)
- get cotton twine from local retail or online from Kreando (Sutz-Lattrigen CH, www.kreando.ch/baecker-garn-uni-natur-weiss)
- get Label-Fix from companies that sell beekeeping equipment. According to the manufacturer Klug Conservation, adhesion on plastics is not guaranteed

Further reading

- for a summary on the state of the art in wet collections, see Meier and Wechsler (2011)
- for a comprehensive reference on fluid preservation, see Simmons (2014, 2019)
- for a set of the latest articles on wet collections, see SPNHC (2020b)
- for labelling material, see NPS (2005c) and Neuhaus et al. (2012)

2.5.1 Glass jar containers

Glass jars are used in two principal ways: either to store single (or several) large objects, or a few to many vials. In this section we will deal with types of jars and not with the vials inside the jars (see 2.5.3). Carter and Walker (1999) list advantages and disadvantages of various jar designs used in natural history collections.

Glass types and their hydrolytic resistance

There are different types of jars in use in natural history collections. They vary in quality, especially with respect to their hydrolytic resistance, i.e. the degree to which they influence the pH of the contained liquid. Simmons (2014) discusses three hydrolytic classes that can be considered for collections.

The highest hydrolytic resistance (class 1, glass type I) includes neutral glasses such as borosilicate glasses (Duran, Pyrex, etc.). They are recommended for use in natural history collections. Still a very high hydrolytic resistance through surface refinement (class 2, glass type II) has soda-lime-silica glass (soda-lime glass), which is used for drinking glasses, also. A medium hydrolytic resistance (class 3, glass type III) contain so called packaging glasses such as jam jars. This is also a type of soda-lime-silica glass (soda-lime glass). However, their hydrolytic resistance is at least ten times lower than the one of type I glass and they are only the third choice.

Ideal borosilicate glass jars

Borosilicate glass is mainly comprised of silicon dioxide (80%) and boron trioxide (5–13%) (plus 4–8% sodium oxide and 2–7% aluminium oxide). Borosilicate glass is used in laboratories due to its high durability and superior chemical and heat resistance. Its low reactivity and low relative weight are valuable characteristics for long-term specimen storage. Borosilicate glass is also significantly more mechanically robust than soda lime glass. Its price is about 3–5 times higher than that of conventional glass jars but is nevertheless the best choice for specimen storage.

Suboptimal soda-lime glass jars

Soda-lime glass, also called soda-lime-silica glass, is the most common type of glass for jars used in the food industry, such as preserving jars. There are two different types of soda-lime glasses, which are differentiated based on their hydrolytic resistance: class 2, i.e. glass type II, used for drinking glasses and class 3, i.e. glass type III, used for jam jars. Due to their relatively low price and availability in various sizes, food preserving jars have also become the most widely used type of glass in wet collections. However, they are relatively heavy and fragile. They are also not thermally or chemically resistant.

All older collection jars with a glass stopper and flat closure with a pork bladder sealing, are made of this glass type and are very fragile. The reuse of such jars should be done with care and by a specialist, as they are very breakable. When restoring historical collections, however, the old glass should be reused for the same objects to preserve, wherever possible, the cultural value of the objects. Exceptions are permitted where it can be shown that the damage will continue to increase if corrective action is not taken.

Do not use plastic jars

Plastic containers are not suitable as storage containers in collections. The only exception is for objects or samples stored temporarily in the laboratory during processing. Liquids can accumulate plastic particles and other contaminants that taint the alcohol and the specimens within. Plastic containers also have a low life span and risk becoming brittle and breaking.

Recommendations

- → use jars and vials made of borosilicate glasses (Duran, Pyrex, etc.), i.e. neutral glasses with the highest hydrolytic resistance for long term specimen storage
- → if borosilicate glasses cannot be used, find soda-lime glass jars of glass type II
- → do not use plastic containers in wet collections

Examples

- type specimens are stored in borosilicate glass jars at the NMB in Basel (see guidelines in Stöckli 2019). Their long-term plan is to switch to borosilicate glass in all wet collections
- to learn about how historical wet collections can be stored in borosilicate glass jars see the 'Steinmann collection' of the NMBE in Bern
- all liquid collections of the Naturkundliche Sammlung Liechtenstein are stored in borosilicate glass jars

Suppliers

- get borosilicate jars from Schmizo Swiss scientific glass (Oftringen CH, www.schmizo.ch) or Dixon Glass Ltd. (London UK, www.dixonglass.co.uk)
- get large-sized borosilicate glasses from Stölzle Oberglas Gmbh (Köflach AT, www.stoelzle.com)
- get Duran glass from SCHOTT Schweiz AG (St. Gallen CH, www.schott.com/schweiz)
- get soda-lime glass jars of type II quality from DKW Life Sciences (Mainz DE, www.dwk.com)

- get soda-lime glass jars of type II quality and twist-off lids from Unitwist (Sarnen CH, www.unitwist.ch)

Further reading

- for a table describing glass types, see Simmons (2014) or Carter and Walker (1999)
- for the effect of container glass quality on pH, see Kotrba and Golbig (2011)
- for details on borosilicate jars, see Wechsler and Meier (2016)

Figure 2.5.2.a: Historic plant collection in glass jars with ground glass joints at the BOGA in Bern (photo Katja Rembold)

2.5.2 Lids and seals

Evaporation is a frequent problem in liquid-fixed collections and may represent a serious danger for some biological groups whose morphology may be permanently damaged by desiccation. In addition, evaporated substances present a security risk and a potential health-hazard for staff. The quality of the lids and seals used to close jars varies considerably and so does their ability to keep preservation liquids from leaking or evaporating. The three most common types of lids are hollow grinding glass lids, screwed lids and hinged lids.

Closing versus 'covering' systems

Glass jar, lid and closing mechanism together form a 'system' which functions in a coordinated manner. Generally, a difference should be made between closing and 'covering'. Placing a lid on a jar without producing a vacuum is not considered as closed but as 'covered' (Anders-Grünewald and Wechsler 2000). In practice, jars are often only covered, especially if the specimens contained within are used frequently. However, for proper long-term storage of specimens, the jars should be closed, i.e. sealed.

A glass is considered to be sealed if the seal is made under negative pressure (Anders-Grünewald and Wechsler 2000). A vacuum closure provides long-term preservation safety. Correct closure by trained personnel allows objects to be stored safely for at least 100 years. The pressure is either generated by heat or by means of a vacuum pump. This sealing technique reduces the residual oxygen content in the jar. Oxygen is a reactive gas and reducing its concentration limits the pH-change in the liquid, thus slowing down the aging process. A positive side-effect of this treatment is a reduced or almost non-existent evaporation.

Hollow grinding glass, i.e. with a ground glass joint

Although ground glass joint systems were mainly used in historical collections, they are still in production (see figure 2.5.2.a). In such a system, the lid and the corresponding jar fit together like a lock and key. Nowadays, these glasses are produced by machines and come in standardised sizes depending on the suppliers. Vaseline is used as a seal between jar and lid. Ground joint stoppers can be sealed warm or 'covered' cold. Alternatively, the hollow grinding glass can be 'covered' with a special grease for ground glass joints called ALSIROL. For a correct application see Anders-Grünewald and Wechsler (2000) and Wechsler and Meier (2016).

Surface ground glass lid

This type of closing system is particularly common in older collections. The lid is often wrapped and tied up in a pig's bladder. This type of glass jar has a flange at the top where a glass pane is glued on (see figure 2.5.2.b). A thinly applied colophony/beeswax mixture is used as adhesive (Anders-Grünewald and Wechsler 2000, Zinke 2011).

In the last 30 years the use of silicone rubber pastes as sealing compounds has become very common. This has the disadvantage that it is permeable to gases. The molec-

Figure 2.5.2.b: A historic 'Planschliffglas' jar, sealed with a resin/wax mixture at the MHNF in Fribourg (photo Michael Maillard)

ular structure of all known plastic sealing compounds is not airtight in the long-term, placing preservative liquids at risk of evaporation and contamination. Despite their simpler application, they are thus not as effective as old resin/wax mixtures (van Dam 1997). This type of glass is suitable when special oversized jars are required as they can be custom built relatively easily. They are manufactured exclusively from borosilicate glass.

Threaded glass with twist-off lids

The most common and least expensive systems are those employing metal screw-top lids. These require much caution in handling and maintenance. If too much force is used when screwing them on, they might not hold tight due to over-twisting. On the positive side, the metal lid is enamel-coated on the outside and lined on the inside with a PVC-free material to ensure a good seal and to protect the metal against corrosion.

The most common systems are threaded jars with metal screw caps, so-called twist-off caps. They are inexpensive to purchase but are costly in terms of collection care and maintenance. The lids are designed as disposable caps. Manufactured for the food industry, twist-off lids can only be sealed tightly in accordance with the food manufacturer's guidelines, if the closure is made with a vacuum. The torque applied during the closing of the jars has no influence on the quality of the closure. If the jar is opened, the lid should be replaced by a new one to ensure the quality of the seal.

Twist-off lids must be provided with corrosion-resistant coating and PVC-free seals. Inserted seals made of PTFE (Teflon washer) are not suitable according to current standards. Although PTFE is considered to be a particularly chemical-resistant plastic, it has the disadvantage of exhibiting cold flow behaviour (deformation due to continuous load) and therefore cannot provide a true seal (Wechsler and Meier 2016). Teflon should thus not be used for sealing jars containing specimens.

Meanwhile, various lids with corrosion-resistant coatings and PVC-free seals that meet the requirements for a sealed closure (e.g. Provalin) are available on the market. However, glass jars, lids and seals should always be purchased from the same manufacturer. Despite glass and lids having the same DIN standard (Deutsche Industrienorm), it is possible that they do not fit together perfectly and therefore leak.

Other lids used to 'cover' jars

If a jar is only to be covered for a short time and no closure is desired, other types of systems can also be used. These include Bakelite lids, which become brittle rather quickly, twist-off lids with a PTFE/Teflon insert to prevent metal corrosion and hinged glass lids. Another widespread type used are the classic preserving jars for food with hinged glass lids and a rubber seal. Replace the rubber seal, which is adequate for food but insufficient for the preservation of liquids used in collections, with acrylonitrile-butadiene rubber (NBR). It is a more chemically resistant and has a similar Shore hardness (describes how soft a plastic is) of 40–50. Other substitute plastics for seals are silicone-rubber (VMQ) or ethylene-propylene-dien-rubber (EPDM), depending on the preservation liquid. Both exhibit very good chemical resistance.

Monitoring evaporation and leaks

Regular monitoring of the level of the preservation liquid in the jars is important to prevent samples from drying out. Formaldehyde solutions can attack seals, causing evaporation or leakage. This advice is particularly important where jars are only 'covered', according to the above definition, and not 'sealed'.

However, if jars are sealed under negative pressure, the risk of evaporation is lower. Nevertheless, the degree of evaporation is an important indication of whether the closure is working or whether it needs to be replaced. It should be noted that evaporation of the liquid is only one side effect of a faulty seal. The most serious problems are the reactions caused by the penetration of oxygen into the jar that may damage the specimens. Acidification often occurs.

The frequency with which jars should be checked depends on the climatic conditions (storage temperature) and the closure of the jars. The current liquid level should be marked with a date to document evaporation. The alcohol content must be measured by a trained person once the liquid level changes. If it falls below 60%, the specimen may rot, as alcohol at such concentrations will no longer effectively preserve the specimen. Under no circumstances should alcohol simply be refilled. If the alcohol concentration is too low, the liquid must be replaced. If the pH value of the old liquid must be raised because of its acidification, the objects must be watered and re-buffered with suitable bases.

Recommendations

- → monitor the liquid content in jars regularly
- → ensure that the correct closing technique is used. Prioritise 'closing' jars over 'covering' them, except in cases where specimens will be consulted regularly
- → pay attention to longevity and other aspects of long-term preservation when buying jars (including the closing device). Short-term financial savings may lead to higher personnel costs for collection maintenance and deterioration of the conserved collection items
- → use PVC-free seals only

Examples

- to monitor the ethanol concentration in fluid preserved specimens, the BNM in Chur uses the two small indicator pill system from Alcomon (Leiden NL, http://alcomon.com)
- a best practice manual, including guidelines and suppliers for wet collection curation, is the 'KUR-Project' written by the Naturkundemuseum Berlin (Neuhaus et al. 2012)
- jars with metal screw-top lids and an extra seal made of PTFE/Teflon between the jar and the lid are in use in the BNM in Chur
- hinged glass lids with custom made acrylonitrile-butadiene rubber (NBR) seals (synonym Nitril and Buna-0) are used in the SNM in Copenhagen

Suppliers

- for PVC-free seals, see Unitwist Smart Packaging (Sarnen CH, www.unitwist.ch)
- see list of suppliers in section 2.5.1

Further reading

- for a detailed discussion on the difference between 'closing'/sealing and 'covering' glass jars, see Wechsler and Meier (2016)

2.5.3 Vials in jars

Taxa typically stored in small separate vials that are stored together in a jar include many insect groups, especially aquatic insects and other invertebrates like spiders, small molluscs and many other mainly soft bodied invertebrates.

The small vials are mainly used to separate individual curatorial units (i.e. a specimen or specimens collected at the same time at the same location) in a jar. Individual vials should contain only specimens collected together. Specimens should not be packed too tightly within the vials, as wings, legs and antennae can break easily (Carter and Walker 1999).

The vials should each include one or more specimens, together with a label. The vial should be closed with cotton so that the preservation liquid can diffuse through. In this way only the jar has to be checked and refilled if the preservation liquid runs low, and not each individual tube. Moreover, cotton does not deteriorate in ethanol. Plastic caps, on the other hand, do eventually deteriorate when exposed to ethanol and will have to be replaced.

If the vials are very small, they may be disorganised within the jar. If they are plugged with cotton wool, it is important to use vials of the same diameter in the jar to prevent a smaller vial from entering a larger one and pushing the cotton plug deeper into the vial (Carter and Walker 1999). Another way of preventing this is to use a generous amount of cotton to tightly seal the vial.

Upright or bottom up storage?

However, if the jar is small, the vials can be placed vertically in the jar in one or two layers (see figure 2.5.3.a). This works especially well if the jars are cylindrical. In this case, the end with the cotton seal should be on top to prevent specimens or free-floating body parts from getting entangled in the cotton and lost when the plug is removed.

There are conflicting opinions on which end of the vial should be upper-most. Carter and Walker (1999) suggest that vials plugged with cotton wool should be inverted in the jars but those with polypropylene caps should be stored upright. In principle, using enough cotton wool will prevent the plug from being lost but polypropylene caps can pop off, allowing specimens to disperse in the preservative. In malacological collections, vials are generally plugged with cotton and are stored bottom-up to minimise loss of liquid.

Labels can damage specimens

Labels should be inside the container with the specimen. Ideally, vials are large enough to prevent the specimen(s) from being damaged. This is especially important if more than one label is in a vial. If possible, the label with most information (including a barcode) should be laid flush against the inner side of the vial but leaving an opening so the specimen remains visible. This way the label and barcode can also be read from the outside, i.e. the labels do not have to be removed from the vial to be read, thereby reducing the risk of damage to the specimen. Tiny objects or detached parts of the specimen should be kept separately from the label, i.e. in a smaller vial or cotton-sealed glass tube within the main vial to avoid loss of parts when removing the label. For label information, content and materials see sections 2.4 and 2.5.

Figure 2.5.3.a: Borosilicate jars with two rows of fitting vials in the ant collection of the NSFL in Triesen (photo Holger Frick)

Use glass vials for long term storage

Ideally, borosilicate vials are used (see section on jars for an explanation). If not available or too expensive, vials made of soda-lime glass are an acceptable choice and are always better than plastic vials, which exhibit low durability and may give off substances that could taint the preservation liquid and thus cause damage to the specimen(s).

In some cases, however, plastic vials may be useful for temporary storage. For example, Eppendorf tubes are sometimes used to collect specimens in the field. The tubes can then be stored temporarily in jars before sorting and transferring their contents into proper glass vials for long term storage.

Recommendations

- → store vials in jars filled with preservation liquids to reduce risk of vials drying out
- → seal vials with cotton plugs, rather than plastic lids, to allow diffusion of preservation liquids
- → store vials vertically with the cotton seal on top (or below for malacological collections)
- → use enough cotton to seal the vial tightly. A small cotton wad may become dislodged and float away
- → use borosilicate glass vials
- → do not use plastic vials due to their low durability
- → put labels in the vial, with the specimen(s). If specimen is very fragile, two vials can be used: a smaller one with the specimen inserted into a larger one with the label

Examples

- small flat bottom vials with a smooth edge, as described above, are in use for the spider collection at the NMBE in Bern
- glass vials, as described in the text,are in use for their wet collections of small specimens at the MZL in Lausanne

Suppliers

- get flat bottom vials (Flachbodenglas, glatter Rand 3. Hyd. Kl. Klar 50 x 15.75 x 0.85 mm) from Alemania Glas GmbH (Meuselbach-Schwarzmühle DE, www.alemania-glas.de)
- get small flat bottom vials (Flachbodenglas 50 x 10 mm × 0.8 mm or 35,5 x 8 mm x 0.5 mm) from the Laborshop24 GmBH (Gross-Zimmern DE, www.laborshop24.de)
- for different sizes and custom-built glass vials see Milan SA (Vernier CH, www.milian.ch)
- get glass tubes of 3- and 4-mm diameter for detached palps from VWR International GmbH (Dietikon CH, https://ch.vwr.com)

2.5.4 Preservation liquids

The most common preservative solutions are 70–80% ethanol and 3–4% formaldehyde. Ethanol is less toxic but highly flammable and exhibits a low flash point. With regard to specimens, ethanol preserves the DNA (see section 2.9.4 for concentrations) but dissolves colour pigments and thus causes decolouration of the specimens. Ethanol preserves tissues if the concentration is above 60%. Its capacity to preserve tissue is related to its ability to remove water, which also increases the risk of shrinkage. The vapour pressure of ethanol is very low, leading to a high rate of evaporation. Collections stored in ethanol must be kept in explosion-proof rooms. Appropriate safety precautions must also be taken when working with such collections, namely with regard to flammability and dangers associated with electrostatic charge (see section 3.2.4).

Formaldehyde solutions, on the other hand, are toxic and considered to be carcinogenic and mutagenic in the EU. Formaldehyde destroys DNA. As an aqueous solution, the vapour pressure is higher than that of ethanol and therefore the rate of evaporation is lower. When working with objects containing formaldehyde, strict occupational safety measures must be enforced.

In historic collections it is often unclear what kind of preservation liquid was used. In the past, poisons such as mercury were also added to the preservatives. Therefore, the greatest precautions should be taken when handling unknown liquids. It must be possible to safely exclude mercury as a component before processing. Formaldehyde can be detected with test sticks.

Ethanol – the preservation liquid of choice

Ethanol is the most widely used preservation liquid today. Not only does it prevent the disintegration of tissues, but in high concentrations it is also suitable for the conservation of DNA (see section 2.9.4). The ideal concentration depends on the purpose and type of collection. The higher the concentration, the more water is removed from the specimen, which leads to better tissue and DNA preservation. However, it also leads to increased hardening, fragility and shrinkage of the object, which may hinder subsequent anatomical investigations. There are many different qualities of ethanol. Pure, non-denatured ethanol (without additives), should be used for liquid preservation. Please note that ethanol expands or contracts about eight times more than water. Therefore, it is important to cover the objects with enough liquid, otherwise there is a risk that the objects will no longer be covered with liquid if they are transported into a cooler room.

Figure 2.5.4.a: Invertebrate wet collection of the MHNG in Geneva (photo Philippe Wagneur)

Safety regulations must be followed when handling ethanol. The work space must be built in accordance with the applicable explosion protection regulations. The problem of electrostatic charge must be taken into account in the storage room. The workroom must have forced ventilation with additional extraction vents near the floor. Nitrile gloves must be worn during work, which must be changed at the intervals specified by the manufacturer. Masks

with an oxygen supply must be worn, depending on the efficiency of the ventilation system.

Formaldehyde to preserve and fix tissues
Formaldehyde is used to preserve and fix tissues in wet collections. To date, no equivalent replacement has been found. In the EU it is classified as both carcinogenic and mutagenic. Special regulations for working with it are derived from this.

It is also listed in the EU's Biocide Regulation and its use is only authorised until 2022. Whether formaldehyde may continue to be used at all after this date for the conservation of natural history objects depends on negotiations between museums and the relevant body within the EU Commission.

Recommendations

- → indicate the type of liquid and its exact concentration on a label in the jar
- → consult a specialist for liquid analyses, if the identity of a liquid is uncertain
- → use 1. quality ethanol, namely A15A Alcohol absolutus to preserve wet collections
- → adjust concentration to the needs of the collection. The concentration should always be above 70%. If below 60%, the tissue deteriorates due to decomposition caused by microorganisms
- → use 99.9% ethanol to conserve DNA
- → use 80% ethanol for insects, spiders etc. At higher concentrations legs etc. break off easily and are likely to be lost
- → use 75% ethanol for vertebrates
- → replace the ethanol of freshly sampled specimens soon after preparation, since the ethanol concentration can drop considerably due to the water present in fresh samples
- → wear suitable protective clothing (a lab coat, protective goggles or a mask with oxygen supply and nitrile gloves) when working with ethanol or formaldehyde
- → transfer samples stored in formaldehyde to ethanol
- → only carry out works with formaldehyde-fixed objects under an extraction hood
- → wear a mask with oxygen supply even if a faint scent of formaldehyde is detectable in a room

Examples
- 75–80% ethanol is used in the MZL in Lausanne to preserve most wet collections and in the NMBE in Bern to preserve its spider collection
- 80–90% ethanol is used in the malacology collection of the NMBE in Bern

Supplier
- to order tax free pure A15A Alcohol absolutus, get a licence for museums from the Federal Customs Administration: Alcohol and tobacco division, i.e. AlcoSuisse (Bern CH, www.alcosuisse.ch)

Further reading
- for a method to distinguish formaldehyde from ethanol, see Waller and McAllister (1987)
- for a guide to maintain ethanol concentrations, see Notton (2010)
- for exposure effects of formaldehyde on staff, see Burroughs et al. (2006)

2.5.5 Changing preservation liquids

Historic wet collections may contain samples preserved with formaldehyde or other preservation fluids. In general, these should be exchanged in favour of other, less toxic fluids following the necessary regulations. Changing or topping up liquids should only be done by trained personnel. Here we give only a general overview and not a step by step hands-on guide to this process.

Liquid and objects interact with each other due to the conservation process. A change in the concentration of a liquid or to the liquid itself must be carried out very carefully, otherwise damage to the preserved object(s) may occur. Careless work can destroy the storage objects (preparations, glasses, labels, caps). Liquids must be analysed, checked and replaced if necessary, or topped up with fluids of the same concentration. If preparations preserved in formaldehyde solutions are to be transferred to alcohol, they must be soaked in water and then transferred in a series of incremental steps (a so-called ethanol series) to the next, more concentrated solution. This means: 20–40–50–60–70% up to the desired final solution concentration. The final solution must be changed at least once. The higher the ethanol content, the stronger the dehydrating effect. The preparations formerly preserved in formaldehyde may therefore shrink considerably when transferred to ethanol, potentially damaging a specimen or its associated structures.

Recommendation

→ consult a specialist to exchange preservation liquids

Example

- to see how a historic wet collection can be reconditioned see the NMBE in Bern and the publication of Neisskenwirth (2019)

Suppliers

- Präparatorium Christoph Meier (Münsingen CH, www.präparatorium.ch)
- Bauer Handels GmbH (Fehraltdorf CH, www.taxidermy.ch)
- Fabian Neisskenwirth

Further reading

- to recondition a wet collection, see Neisskenwirth (2019)
- to transfer specimens from formaldehyde to ethanol, see Moore (2001), Mulder (1997) or Bayless and Shepherd (1993)
- for the handling of dehydrated insect specimens, see Singer (2014)

Figure 2.5.5.a: Changing preservation liquids in the NMBE in Bern (photo Lisa Schäublin)

2.6 Dried botanical specimens

The classic technique of preserving plants, algae and fungi is via drying. As early as 1551, the Italian naturalist Luca Ghini (1490–1556) prepared the first herbarium and his original method has more or less remained unchanged until the present day. For vascular plants, the technique of drying was combined with the application of pressure to flatten the material, with specimens then mounted onto sturdy paper sheets or thin boards. This allows for a more effective, space-saving form of storage of specimens in horizontally layered piles. In earlier times, pressed specimens were often mounted in bound books (e.g. the herbaria of Johann Jakob Scheuchzer [1672–1733], Johannes Gessner [1709–1790] and Albrecht von Haller [1708–1777]). Other groups of organisms, like fungi or bryophytes, are normally air-dried without pressing because the material loses considerable information if the original form is not preserved. Air-dried un-pressed objects need to be stored in cardboard boxes or the appropriate types of packets.

Storing information with the specimen

Materials used and techniques applied to specimen preservation must be selected with the intention of lasting for centuries. This applies to the safe-guarding of information and assuring the association between mounted plant material and label information. A well-documented contemporary plant specimen consists of the entirety of the original plant material, or representative samples taken from different parts of the same plant for large or woody species, together with detailed label information attached to the sheet or the box containing the specimen. This accompanying label, and possibly also image information, contains data about where the plant was located at the time it was collected, who collected it and as much information as possible concerning the original organism, especially that which may not have been preserved with the specimen (e.g. flower colour, height of the plant, ecological habitat).

Figure 2.6.a: Herbarium of the MNVS in Sion (photo Jacqueline Détraz-Méroz).

Mounting specimens

Mounting and storing specimens for safekeeping in a voucher collection ('Belegsammlung') is resource intensive. A properly mounted specimen ideally displays the most important taxonomic characters of the plant group, while simultaneously offering full visibility of the attached labels. Un-pressed plant material is either stored in sturdy boxes (e.g. macrofungi, bulky vegetative organs, large fruits) or in paperpackets (e.g. bryophytes). The fundamental guidelines on how to mount plant material are explained in detail by Bridson and Forman (2000). Further explanations of different methods, illustrated by informative colour plates, are presented by Victor et al. (2004). The latter publication also proposes full details on the mounting and storage of bryophytes and lichens. In the case of bulky plant material, often associated with plant families displaying massive floral or vegetative structures (e. g. Arecaceae, Pandanaceae), mounting may be replaced by the storage of the specimen in cardboard folders. Details on specific plant mounting materials and the necessary equipment or tools employed by the technical staff have been described by Singh and Subramaniam (2008) and Stauffer and Gautier (2014).

Further reading

- for a general overview, see the standard manual of Bridson and Forman (2000)
- for details on plant mounting, see Sing and Subramaniam (2008) and Stauffer and Gautier (2014)
- for further details on different methods, see Victor et al. (2004)

Figure 2.6.1.a: Historic herbarium sheet of the Z+ZT in Zürich (photo Reto Nyffeler)

2.6.1 Pressed herbarium specimens

After collection, vascular plants and large multicellular algae are pressed and dried as quickly as possible to avoid infestation with mould and in order to preserve original colours as far as possible. Specific recommendations for preparing or dissecting parts of the plant or algae for pressing are given by Bridson and Forman (2000) or in the special literature on the particular groups. It is important to note all relevant accompanying information on the label associated with the mounted specimen.

Mounting paper and boards

Dried and pressed plant specimens are mounted on sturdy paper sheets, applying different methods of fixing the plant material onto the supporting paper or board (see figure 2.6.1.a). Mounting techniques that allow for future removal of the plants from the sheets for examination, without causing any damage, are preferable. Therefore, mounting with glue or covering the specimen with self-adhesive transparent plastic sheets is to be avoided, even though the latter is an effective precaution against insect pests. Most often, gummed paper strips, or, more rarely these days, pins, are used for mounting. Plants need to be fixed onto the paper sheets at as many points as needed to stabilise the specimen and to hold together plant parts that may potentially become detached by repeated examinations.

Mounting paper or board is generally between 41–44 cm in length and 26–29 cm in width. These days, making use of the A3 format may be a more practical choice. Paper weight should be between 160g/m^2 and 250g/m^2, and needs to be optimised to take into account both the weight of the growing piles of specimens and the stability of the individual sheets against bending when manipulated.

Some herbaria mount specimens in folded paper sheets (paper weight around 160g/m^2), with additional single sheets added to the specimen folder if the collection consists of plenty of material that can be mounted separately. This results in a significant increase in the weight of the specimen piles. Other herbaria, for reasons of protection or for grouping like specimens, use folded paper folders of the same format to collect individual sheets together.

Preferably, the paper to be used should be off-white, which will facilitate any future digitisation initiatives as white paper affects scanning. Brownish paper was used in the past, but has unsatisfactory archival qualities. Thus, coloured paper should be avoided for preservation reasons. The paper should be free of acids and chlorine substances.

Labels

Labels provide written information that supplements the preserved plant material and primarily provides information about where and when the specimen was collected and by whom, as well as any intrinsic characters that may be lost with the preservation like colour and smell, features of the habitat conditions at the collection locality and a code to allow for the unique identification of the specimen (i.e. unique catalogue numbers, barcodes, id records), independent of its taxonomic identification.

Any written information should be printed/written with permanent ink or pencil, although the latter is often not clearly visible on photographs of specimens. Hence, the use of China Ink is preferred. These days, labels prepared using computers should be printed on acid-free paper using laser printers that apply black toner. Ink-jet printers should not be used.

For herbarium specimens, at least two labels should be mandatory: first, a label containing all information relevant to the specimen and second, an acquisition label indicating the date of entry into the collection. Other annotation labels will typically include new identifications or type designations, indicating that scientists have conducted research using the specimen. Other labels are also added if destructive sampling has been performed on the specimen (extraction for microscopic preparations or, increasingly importantly, for DNA sequencing), indicating who has performed the sampling, when it was done and what it was intended for (research project name). Additional labels may include digital identifiers (linear barcodes or 2D QR-codes).

Paper packets (envelopes) for loose parts

A small packet attached to the principal sheet of a specimen can be used to hold loose parts, either if they are too small to be mounted onto the sheet or if they have fallen off, but can be clearly associated with the particular specimen. Such packets come in a variety of sizes but are generally between 5 × 5 cm and 15 × 10 cm when closed. Further details about folding the paper for packets are given by Bridson and Forman (2000).

Figure 2.6.1.b: Piles of herbarium sheets in cardboard boxes in the CJBG in Geneva (photo CJBG)

Storing piles of herbarium sheets
The main interest in using boxes to store herbarium specimens is to prevent mechanical damage. Boxes reduce the risk that specimens will fall, lose fragments, or suffer mechanical damage when they are moved. Boxes also facilitate the rapid evacuation of specimens during fire or flooding.

It is tempting, however, to overload boxes with large numbers of specimens, which may cause mechanical damage to specimens at the bottom of the box. Overloading boxes may also make it more difficult to find a specimen and they need to be removed in multiple, small bundles. It is essential that specimens are contained within folders that facilitate sliding specimen piles in- and out of the box. Finally, it is useful if specimen folders within boxes have a label that can be read while in the pile (a 'tongue' that overhangs the pile and is folded forward).

In contrast, piles of specimens stored in compartments on open shelves (e.g. in movable compactor systems) should be supported with a sturdy cardboard (400g/m^2) layer at the bottom of the pile, preferably with a short strap loop at the front side for easy handling of the pile. Mounted specimens should always be handled with a study cardboard layer underneath them to avoid bending the mounted material.

Piles can be up to 20 cm in height
Specimens mounted on paper sheets may be stored horizontally in piles of up to 20 cm in height (see figure 2.6.1.b). Piles should be stable and the overall weight of them should be monitored to assure that they do not become heavier than a few kilograms to avoid specimen damage by compaction (consider also health issues of technicians handling specimen piles as part of their curatorial work).

If a collection is to be barcoded and scanned, extra storage space may be required. The inclusion of barcodes on specimens may increase the height of the pile.

Recommendations

- → attach labels directly to the herbarium sheet in the bottom right corner with traditional white paper glue
- → mount specimens on acid-free off-white paper, with a weight between 160g/m^2 – 250g/m^2, a length between 41 – 44 cm, and a width between 26 – 29 cm, or A3 format
- → keep piles below 20 cm in height and store them in boxes

Examples
- folded herbarium sheets of 135 g/m^2 weight, 43.5 × 27.5 cm, unfolded herbarium sheets of 280g/m^2 weight, 43.5 × 26.0 cm and cardboard folders of 240g/m^2 weight, 43.5 × 28.0 cm are used in the BNM in Chur
- chlorine and acid-free hard cardboard boxes of 48.0 × 33.0 cm and 14.7 cm high, containing about 60 herbarium sheets apiece are in use at the MNVS in Sion. Each box has a label with the contents
- acid-free cardboard boxes of 53 × 33 cm and 20 cm high are used at the Naturmuseum St.Gallen
- for an example on plant mounting practices in the CJBG in Geneva, see Stauffer and Gautier (2014)

Suppliers
- get acid-free herbarium sheets and cardboard boxes from Oekopack Conservus AG (Spiez CH, www.oekopack.ch) or Tschudi + Cie AG (Netstal CH, www.tschudi.com)

Further reading
- for further details see Bridson and Forman (2000)

2.6.2 Pressed specimens in historical bound books

The herbarium of Felix Platter (1536–1614), as well as those of a number of other naturalists of the 17th and 18th century, was bound in large (folio) books, often accompanied with letters or pages with woodcuts from printed books but without any further information on where and when the material was collected (see figure 2.6.2.a). The primary motivation of such an herbarium was often to achieve an ideal representation of nature, and also perhaps an aesthetically pleasing presentation, in keeping with most collections from before 1800.

A further tradition of presenting dried and pressed plant material in bound books arose in the second part of the 19th century, when attractive alpine plants were mounted in smaller books to illustrate the diversity of such plants. These small albums were sold to tourists in alpine recreation areas in the Engadin or the Bernese Alps.

Bound books with mounted plants should be stored horizontally and should be protected by keeping them in acid-buffered boxes of a size close to the format of the book, but with a few centimetres extra on each side. This allows the books to be removed and put back without touching or chafing the book. Acid-free tissue paper can be used to stabilise the books in the box.

Figure 2.6.2.a: One of more than 200 volumes of the 'Weltherbar' by Johann Conrad Rehsteiner (1797–1858). The Herbarium in form of bound book from the NMSG in St. Gallen includes more than 20,000 sheets (photo Chris Mansfield)

2.6.3 Bulky wood and fruit samples in boxes

A bulk collection supplements those specimens mounted on paper sheets with plant parts that are not possible to mount together with the pressed material (see figure 2.6.3.a). The classical example is a palm specimen where the leaves are mounted on paper herbarium sheets and the fruit (coconut) is maintained in a separate bulk collection. In general, these collections include fruits and seeds, the collection of massive vegetative organs that are critical for taxonomic identification in the plant group (e.g. long petioles and leaf sheaths) and the xylarium (e.g. wood like stem cross- and longitudinal sections or bark samples).

Bulk collections should be stored close to the shelves where the herbarium specimens mounted on paper sheets are stored and not in separate rooms, to assure the association between all of the material derived from a single specimen. The labels on the bulk collection, preferably a copy of the original, should be identical to those on the sheet specimen. Furthermore, the existence of bulk material should be noted on the herbarium sheet.

Bulk material should be stored in cardboard boxes with lids. Ideally, such boxes are of different sizes, where the dimensions of the smaller boxes are a fraction of those of the larger boxes, thus facilitating storage. Acid-free tissue paper can be used to stabilise the objects in the box.

Recommendations

- → preserve bulk specimen in boxes, with padding to prevent objects from moving around in the box
- → attach a copy of the original label to the bulk specimen, and indicate its presence on the associated herbarium sheet
- → digitise bulk collections, as they often host important type material, and can frequently be more informative than the associated herbarium sheets
- → store fruits, seeds and wood samples close to the regular collection in order to guarantee full access of the material by research visitors. Bulky collections are often neglected if not easily accessible

Example

- pieces of wood are stored in plastic RAKO boxes without lids on the shelves at the MNVS in Sion

Supplier

- find RAKO-boxes at Georg Utz AG (Bremgarten CH, www.utzgroup.ch)

2.6.4 Cryptogamic specimens in packets

Mosses, hornworts and liverworts (bryophytes), as well as certain macro-fungi and lichens, are usually air-dried but are not pressed. Once dried, they may be stored in acid-free paper packets (envelopes) of different sizes. It is good practice to decide on a few different standard sizes to accommodate specimens of different proportions. Providers of pre-folded, custom-made packets require the full set of dimensions in order to set the cutting dies, which can be reused for subsequent orders.

Alternatively, packets can be folded from A3 or A4 acid-free paper sheets, applying the folding pattern as detailed in Bridson and Forman (2000). Pre-printed or hand-written labels are glued to the specimen packets prior to the specimens being placed inside. Alternatively, label information can be printed directly onto the A3 or A4 sheets before folding. The packets can be mounted, horizontally, on standard herbarium sheets (ideally affixed using pins so that specimens can be removed for examination or moved between different sheets) that are kept within herbarium folders which are stacked in piles. They can also be stacked within an herbarium folder in loose layered piles of A3 size, with a sturdy, underlying cardboard support, or they can be stored vertically in long, narrow boxes like those used to store index cards, or in filing cabinets with appropriately sized drawers.

Examples

- collections of mosses and lichens at the MNVS in Sion are stored in ad hoc sized packets made by folding non-acidic paper, with an integrated label
- algae, parasitic basidiomycetes, bryophytes, ferns, lichens, and other groups in the cryptogamic collection at the CJBG in Geneva number some 1–1.5 million specimens. Within each taxonomic group, the specimens are alphabetically arranged by genus and within each genus alphabetically by species. Specimens are placed in packets that are pinned onto herbarium sheets that are stored within herbarium folders, in stacks of 10–15 cm high. Ferns are mounted using the same methods as for gymnosperms and angiosperms (see section 2.6.1). Large, bulky specimens or specimens that are fragile are stored in boxes (see figure 2.6.5.a)
- museum paper of quality 15, light white, 120 g/m^2 weight and custom-sized is used in the BNM in Chur

Figure 2.6.3.a: Bulky seeds at the BOGA in Bern (photo Katja Rembold)

Figure 2.6.5.a: Fungi collection of Jean-Pierre Prongué including several thousand specimens archived in the NSFL in Triesen (photo Holger Frick)

2.6.5 Dried fungi in glass jars, trays or boxes

The fruiting bodies (sporocarps) of macrofungi are dried and then stored in boxes or glass jars, applying similar techniques as those used for bulky parts of vascular plants (see figure 2.6.5.a). Samples of spores collected during the preservation process should be gathered in small packets and stored together with the macrofungi.

Macrofungi may be placed in Ziploc bags that are tightly sealed with as much air removed as possible. This requires well-dried specimens and for packing to be performed under conditions of low humidity to avoid degradation of the material in the closed bags. Packing specimens in sealed bags also provides some degree of protection against pest (beetle) infestations.

Microfungi of various taxonomic groups should be stored in a dried state together with the material of their hosts or substrate. Again, well-dried samples may be stored in sealed plastic bags, which are placed in sturdy cardboard boxes to avoid mechanical pressure that may result if specimens are piled on top of each other. Alternatively, some samples may be pinned onto cork layers, which then are stored in boxes.

Example

- depending on their size and their morphology, the CJBG in Geneva protects its mycological specimens either within paper packets, or on single sheets, all of them organised in cardboard folders, or in boxes. Non-parasitic basidiomycetes and the myxomycetes are stored in small modular cardboard boxes and extremely small specimens in matchbox boxes. All of them are in turn stored in larger cardboard boxes in which they are tightly packed

Further reading

- for further information see Bridson and Forman (2000) or Prance and Fechner (2017)

2.7 Dried zoologial specimens

Similar to other collections, dry zoological specimens should only be in contact with acid-free and unbuffered materials. This refers to the surface on which large specimens are stored, the containers they are stored in, the labels that carry the information about the specimen and how those labels are attached to the specimen. For general information on the content of labels and label materials, see section 2.4. Specific information on storage materials and compartments are mentioned directly in the following sections.

2.7.1 Closed trays and boxes for fragile specimens

There are many types of delicate specimens that should be stored in covered boxes. If the boxes are not transparent, a picture of the specimen may be attached on the outside with a copy of the label. Examples include delicate echinoderms that are traditionally stored in glass-topped boxes or covered Polystyrol boxes similar to those used for mollusc shells. Fragile specimens can be protected from damage by careful cushioning with cotton wool or acid-free tissue paper (Carter and Walker 1999).

Bird eggs

Eggs should be stored on acid-free cotton wool, in drawers, in acid-free cardboard boxes, Ethafoam or in acid-free glass boxes (see figure 2.7.1.a). An acid film, capable of attacking and destroying egg shells, may develop on the surface of soda-lime glass. This type of glass should thus be avoided in egg collections. Each egg in a collection should carry a catalogue number handwritten in China Ink to prevent any mistake when several clutches are examined together. The label should be placed within the case containing the clutch, ideally fixed firmly to the storage container. Like all preparations, eggs are sensitive to light, which changes their pigmentation.

Malacological specimens

Shells mainly consist of calcium carbonate and as such are damaged by any acidic environment. A major threat

Figure 2.7.1.a: Blackbird eggs placed on cotton wool in the NMBE in Bern (photo Lisa Schäublin)

Figure 2.7.1.b: Malacological collection at the NMBE in Bern (photo Estée Bochud)

to shell collections is Byne's disease – an efflorescence (white powder) resulting from reactions with organic acid vapours released from wood, acidic glass and other materials found in storage cabinets (Carter and Walker 1999). For prevention, especially small, delicate specimens should be removed from old jars and transferred to acid-free jars (see figure 2.7.1.b), such as those made of borosilicate, or to polystyrene vials and boxes (Petrak 2016). Another source of harmful acids is oak wood. Drawers made of oak should be replaced with metal or beech wood drawers. If shells are already coated with a white powder, it can be carefully removed with a fine brush. In modern shell collections, individual specimens are often enclosed in polyethylene, i.e. polythene (PE) bags and stored in open unit trays (Carter and Walker 1999). Alternatively, they may also be placed in polystyrene tubes or acid-free cardboard boxes.

All shells should be protected against dust by storage in acid-free tubes, boxes or other containers of appropriate size. Containers made from polystyrene are the most efficient, as they are transparent, lightweight, robust, and affordable. Tubes are traditionally closed with a small cotton pad, which can be made of synthetic fibres to avoid infestation by cotton insects. The size of the container should be as small as possible while still generously accommodating the size of the object.

Labels should be arranged within the tube following the right-hand rule: add items to the tube always with the open end pointing to the right, first deposit the labels so that you can read them through the glass wall, then add the specimens, and finally the plug.

Recommendations

- → use polystyrene or acid-free glass made of borosilicate
- → use acid-free cardboard boxes if specimens are in direct contact with the box
- → store specimens in the dark to avoid degradation of colours
- → avoid non-acid-free cotton, cork and non-archival plastics and use acid-free paper for labels and tags
- → use acid-free cotton to bed eggs and to hold eggs still when the drawer is opened
- → store clutches of eggs in acid-free cardboard boxes or Ethafoam
- → use polystyrene boxes with lids and a lining of cotton or acid-free tissue paper to protect larger malacological specimens
- → place small malacological specimens in polystyrene vials and group them together in polystyrene boxes to prevent movement and collisions

Examples

- Werner Haller's egg collection, held at the MHNG in Geneva and partly at the NMBE in Bern is richly documented and fully digitised (see figure 2.7.1.a)
- for their malacological collections, the NMBE in Bern uses three sizes of polysterene tubes of 55 × 11.5 mm, 50 × 16 mm and 50 × 19 mm to fit well (without rolling around loosely) in standardised closed polysterene boxes of 92 × 59 × 25 mm, 56 × 56 × 27 mm and 56 × 44 × 16 mm. The different box widths are similar to allow a uniform arrangement in the drawer or subdivision with dividers

Suppliers

- find all sizes of polystyrene boxes and tubes at Semadeni AG (Ostermundigen CH, www.semadeni.com) or Bock Pack (Lauterbach DE, www.bock-verpackungen.de)

2.7.2 Pinned arthropods

Dry samples of arthropods and associated labels are traditionally stored on pins. Dry conservation is generally used for more heavily sclerotised specimens. For long-term storage, pins made from stainless steel with forged metal heads are best. Pins with nylon heads are a cheap alternative but the heads often loosen with time, running the risk of damaging specimens. Pins used in historic collections often contain copper and interact with acidic environments, such as the fatty acids found in the insect's body, thereby generating green crystalline deposits called verdigris. Verdigris can develop rapidly and eventually destroy specimens, especially at high temperatures and in high humidity. Verdigris can be removed from specimens by careful brushing.

Collection environment

To prevent damage caused by mould, dry arthropods should be stored at 40–50% relative humidity (Carter and Walker 1999). If chemical pest control was implemented in a collection (forbidden since 2017), the temperature can be around 20°C. Without chemical pest control, storage at 13–15°C is optimal both for the maintenance of the specimens and to prevent the survival and reproduction of pest organisms. As the colours of most arthropods fade when exposed to UV light, specimens should be kept in a dark place. For details see sections 3.2.2 and 3.2.3.

Drawers with unit trays

Historically, pinned entomological specimens were kept in drawers prepared with a layer of cork at the bottom, which allowed specimens to be pinned directly into the drawer. The acidity of the cork, however, eventually contributed to the degradation of pins, labels and specimens. Now, cork has been almost universally replaced by inexpensive, non-reactive Plastazote foam (see below for suppliers).

While pinning specimens directly into a drawer maximises the storage capacity of the drawer, moving specimens from one drawer to another is time consuming and requires the manipulation of each specimen, increasing the risk of breakage. In recent decades, a transition was made to the use of entomological drawers outfitted with unit tray systems (see figure 2.7.2.a). Unit trays are a series of open-top cardboard boxes of varying sizes that fit into standard-sized entomological drawers. Each unit tray has a layer of Plastazote foam at the bottom and specimens may be pinned in the unit trays. Moving specimens is thus done by moving unit trays, which takes less time and requires less manipulation than if specimens were transferred one by one. Unit trays may be either made of sturdy, acid-free cardboard or acid-free plastic.

Preparation of specimens

Specimens that arrive alive need to be killed and prepared. Killing is mostly done with chemicals such as ethyl acetate or potassium cyanide, or by freezing. Preparation

Figure 2.7.2.a: Insect drawer with unit trays in the ETHZ-ENT in Zürich (photo Michael Greeff)

of the specimen should be done before rigor mortis sets in, otherwise specimens will require relaxing (Schauff 2001). Larger or soft-bodied specimens require stuffing with non-acidic fibres, such as hemp, to prevent rotting. If specimens are pinned, the pin should stick out by about one centimetre above the specimen. Stainless-steel pins of size one to five are best, depending on the size of the specimen. The appendages of the specimen are then arranged on a spreading board by fixing the extremities with pins in the desired position. In Lepidoptera, wings are held down with glassine paper strips, which are fixed by pins. The stretched preparation is then placed in a dark, dry, well-ventilated location at room temperature for several days, or in an oven at 40–50°C for one to two days. An alternative to pinning is 'pointing', a technique mostly used for small specimens that would be destroyed if pierced by an insect pin. In pointing, insects are glued to small pieces of cardboard which are themselves mounted on a pin.

Labelling pinned insects

According to Carter and Walker (1999), labels should be kept as small as possible and not greatly exceed the area taken up by the specimen. Often this is a size of around 12 × 8 mm (see figure 2.7.2.b). Several labels can be attached below each other at a distance of 5 mm using a label stair. Attach the location label at the top and the determination label at the bottom of the needle. The minimum data required, as well as appropriately sized labels, are shown in figure 2.7.2.b.

Labels are ideally made using acid-free archival quality paper (card stock) of > 120 g/m² weight. Labels made with ordinary weight paper quickly loosen, rotate around the pin and may eventually fall off. Heavy-weight card stock is more durable, holds its place better on a pin and is generally more resistant if one needs to remove a label and then replace it (for example, when photographing specimens). For specimens pinned with small entomological pins (size 0 or smaller) or for older specimens with fragile pins, card stock may be difficult to pierce easily and may cause the pins to bend or break. In this case, a preliminary guide hole may be made using a smaller size pin before inserting the pinned specimen. Label printing should be done with a laser-jet printer in as high a resolution as possible. Labels should be printed in a standard non-serif font (e.g. Helvetica) in approximately 4-point size.

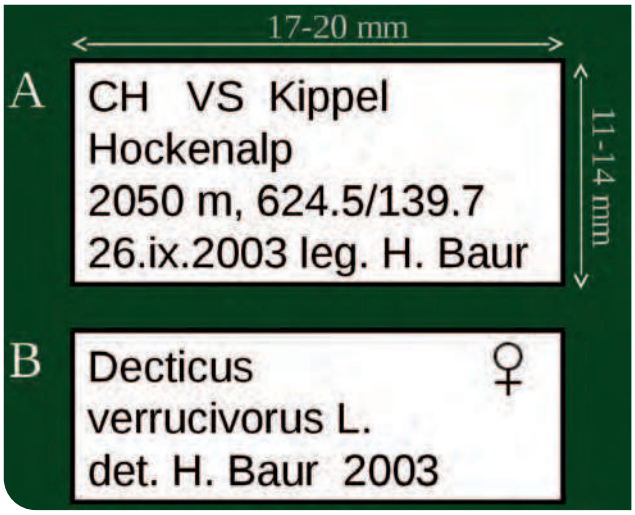

Figure 2.7.2.b: Typical 'locality' (A) and 'identification' (B) labels for pinned insects in the NMBE in Bern (photo Lisa Schäublin)

Recommendations

- → use stainless steel pins, ideally with forged metal heads
- → use Plastazote foam as lining in entomological drawers or unit trays
- → use unit trays for maximum flexibility in arranging specimens in drawers
- → wood-framed glass lids must fit well to keep out pests
- → use one standard size of drawers, especially when working with unit trays
- → never use very thin pins for preparation (i.e. smaller than no. 0)

Suppliers

- get stainless steel pins with forged metal heads, unfortunately only in two sizes, from Watkins and Doncaster (Leominster UK, www.watdon.co.uk)
- get drawers, unit trays, pins and other entomological equipment from Paradox Company Dariusz Skibiński (Krakau PL, www.insectnet.eu), Bioform (Nürnberg DE, www.bioform.de) or Entomologie Meier (München DE, www.ento-meier.de)
- get drawers from Tischlerei Dieter Schunke Entomologische Erzeugnisse (Wolferstedt DE, https://shop.schunke-tischlerei.de)

Further reading

- for detailed information on preservation of zoological collections, see Carter and Walker (1999)
- for a hands-on guide on insect preparation, see Baur (2021)

2.7.3 Papered specimens

Many museums hold collections of unmounted insect specimens in glassine packets in which they were temporarily stored in the field (see figure 2.7.3.a). Glassine paper is acid-free, semi-transparent and does not build up static charge. Usually papered specimens are dried Lepidoptera or Odonata, with their wings folded upwards and information written on the packet. Papered specimens can be pinned later (Schauff 2001) but permanent preservation in the original packets is also possible, saving space, for example, in filing cabinets or cardboard boxes (Caspers et al. 2019). To prevent damage, the individual packets should not be packed too tightly together. Papered specimens are especially vulnerable to insect pest attack and must be checked frequently (Carter and Walker 1999). As far as temperature and humidity is concerned, they may be preserved in the same way as pinned (dry) specimens (see section 2.7.2).

Example

- for procedures on the digitisation of papered specimens and permanent storage in glassine packets, see Naturalis Biodiversity Center in Leiden, Netherlands (Caspers et al. 2019)

Figure 2.7.3.a: Papered butterflies at the NMBE in Bern (photo Hannes Baur)

2.7.4 Storage of vertebrates on racks, in open trays or in boxes

It is common to store large specimens, like most vertebrates or larger invertebrates directly on a rack or in open compartments like trays or boxes on the rack. In this section, we discuss the appropriate measures for proper long-term storage.

Some taxon independent aspects

To optimise storage of vertebrate specimens, they should have sufficient space on the collection shelves and they must not touch other specimens. Each specimen should be removable without having to move any neighbouring objects. They should also be stable on the shelves, which can be assured by fixing the objects on firm, properly-sized bases (made of e.g. untreated three-ply spruce board). An appropriate base should be wider than the width of the object. The object's label should be clearly visible. In addition to the collection label, each object should be labelled with the collection number on the underside of the base. This is useful in case labels are removed or lost. Both labels and the inscriptions on the base of the object should be written in pencil or China Ink. Use acid-free, unbuffered materials for bases, twine and labels, if possible.

Protection of unmounted specimens like amphibians

Specimens should not come into direct contact with shelving. Large unmounted items can be placed on Ethafoam which is widely used in cultural history collections. Ideal, but not necessary, is the placement of a layer of soft, non-woven Tyvek® between the Ethafoam and the object. Unmounted specimens can also be stored in the open (covered with silk paper or a glass cover) or in acid-free open cardboard boxes. If they are closed, a photograph should be attached to the outside.

Sensitive specimens like fishes and reptiles

Preserved specimens and casts with uneven and sensitive surfaces, such as scales, are very delicate and sensitive to dust and mechanical stress. The protruding fins can break off easily. Correspondingly, in addition to the recommendations below, they should be stored in a dust free environment and specifically protected from mechanical damage.

Mounted bird specifics

Mounted birds can be stored on any surface as long as only the platform is in contact with the surface. A plastic cover (of acid-free material) can be used for dust protection if the specimen is too big to be placed in a closed compactor system, but in this case a frame should be placed around the specimen to prevent the plastic from compressing the plumage.

Figure 2.7.4.a: Mounted birds on a branch attached to a platform in the MHNF in Fribourg (photo Michael Maillard)

Specimens with long tails, like pheasants, should be elevated or suspended to prevent the tail from touching the ground. Specimens mounted in flight should be hung rather than placed upside-down on a surface. If they are just laid on their backs, mechanical damage to the feathers will result.

Bird skins

Ideally bird study skins should be stored vertically. For this purpose, specialised staff can mount the specimen on a stick that enters the body (see figure 2.7.4.b). The mounting stick may be used, either to hang the specimen or to secure the specimen in an appropriate platform. This storage technique prevents mechanical damage to the plumage.

However, bird study skins are traditionally stored horizontally in drawers. If this storage method is preferred, acid-free, unbuffered cardboard should be placed at the base of the drawer so the specimen does not come into contact with the drawer itself. Birds should be placed on their backs so that the label attached to their feet remains visible without having to move the object. Ideally the specimens should be wrapped in acid-free tissue paper in such a way that the specimens do not come into contact with each other, although in large collections the specimens are simply spaced within the drawer.

If the bird study skins are prepared with an open wing, which allows detailed examination of primary and secondary specimens like feathers, as well as the inner wing surface, the standing or hanging version is preferable to the lying one. If the wing has been separated from the body, it may be stored under the specimen. Acid-free tissue paper should be placed between the specimens to reduce mechanical stress on the feathers. Individual feathers or wings are best stored in acid-free paper packets, which in turn are stored in acid-free cardboard boxes (Winker 2000).

Mammal skins

Mammal skins can either be mounted around a flat or round support structure or prepared as a flat skin. For a flat support, small mammals are mounted on acid-free cardboard and can be stored, lying horizontally, in a drawer in PE foil tubes (see figure 2.7.4.c). Starting from the size of martens, thin (app. 3–5 mm) untreated plywood should be used. The specimen can be hung on the wood

Figure 2.7.4.b: Horizontal storage of bird study skins in the MHNG in Geneva (photo Philippe Wagneur)

or stored lying horizontally in a drawer. Specimens with a round support are only produced up to the size of martens. They can be stored lying horizontally in drawers.

Small flat skins and furs can be stored in stackable acid-free unbuffered cardboard boxes. Place acid-free, unbuffered tissue paper between the skins, like Tyvek® Soft Non-Woven. Large, unmounted mammal skins are best stored on a horizontal surface and not hanging up. Old skins can fall apart under their own weight due to chemical reactions in the skins, i.e. acid hydrolysis, that weaken the tissues. If skins are stored lying horizontally, hair shifts will occur in any case. To avoid dust on the skins, the mounted skins can also be covered with Tyvek® Soft Non-Woven.

Head mounts and trophies of mammals

Head mounts and trophies require the same storage conditions as other mounted specimens. However, they should be hung on perforated metal walls rather than on a rack, because a head mount is very unstable if placed on a rack (see figure 2.7.4.d). The risk of moving/falling is high. If these walls are part of a movable compactor system, pieces of felt or Ethafoam should be placed between the mount and the wall to reduce vibrations during use of the system. Felt pieces can also be glued directly onto the wooden support of the head mount. Be cautious with the ears, since they are fragile and exposed.

Figure 2.7.4.c: Shrew skins prepared on flat cardboard in the NMBE in Bern (photo Lisa Schäublin)

Figure 2.7.4.d: Storing head mounts on a wall in the MHNF in Fribourg (photo Michael Maillard)

Nests of birds and wasps
Bird and wasp nests are one of the largest pest reserves in natural history collections and require an intense integrated pest management. This should be kept in mind when storing such items. Nests should be stored in a separate room, as cool and dry as possible. Loose nests should not be stored in movable compactor systems because vibrations cause them to disintegrate.

It is thus better to place nests into wells in Ethafoam and store them in acid-free cardboard boxes. This prevents them from falling apart and several nests can be stored together in one standard-sized box, which should be labelled on the outside. Large nests attached to branches can be mounted upright on platforms or in system containers and should be moved as little as possible.

Skeletons, bones and skulls
Mounted skeletons are fragile and require adequate space to prevent breakages. Large skulls and bones should bear a catalogue number, written by hand, in China Ink. If the bone is smooth the catalogue number can be written directly on the bone without a primer. If the bone is rough and porous it can be written on a layer of a primer, like Paraloid (B72, dissolved in ethyl acetate, 15%) to avoid dissolving of the ink. The bones can be placed on racks on a layer of acid-free, unbuffered material or in an open, acid-free cardboard box.

Smaller specimens are better placed in drawers rather than on racks. In this case, 'small' refers to bone fragments, small skulls and teeth, which are easily lost and should therefore be stored in vacume-sealed Polyethylene bags or acid-free cardboard boxes. Parts of disintegrated skeletons should be kept in separate bags placed together in one larger bag. Small skulls can also be stored in transparent polystyrene boxes.

Fragile archaeozoological bones, mammoth teeth and ivory
These objects are very sensitive to vibrations and should therefore not be stored in movable compactor systems. Place them in acid-free, unbuffered cardboard boxes or on shelves covered with acid-free, unbuffered materials. See section 2.8.4 on mammoth fossils.

Figure 2.7.4.e: Mammal skeletons in the ZMZ in Zürich (photo Dennis Hansen)

Recommendations

- → store specimens with sufficient space around them
- → store specimens so that they do not touch each other, minimising risk of breakage
- → store specimens so that each specimen can be removed without moving neighbouring objects
- → use acid-free (and if possible unbuffered) materials only, especially if they are in contact with the specimen
- → for protection and stability, fix each object on a solid base that is wider than the object itself
- → place unmounted specimens on an acid-free material like Ethafoam, silk paper, acid-free cardboard or Tyvek® Soft Non-Woven
- → label the objects clearly using OSTEO-FIX as a primer and China Ink on the label
- → in addition to the label attached to the specimen, objects should also be labelled with a catalogue number on the underside of the base using China Ink or pencil
- → use Ethafoam and silk paper to protect larger specimens

Example

- to see different kinds of mounted and unmounted vertebrate preparations, visit the collections of the NMBE in Bern

Suppliers

- get Ethafoam from Digipack AG (Wetzikon CH, www.digipack.ch)
- get acid and buffer free silkpaper from Antalis AG (Lupfig CH, www.antalis.ch) or Deffner and Johann (Röthlein DE, www.deffner-johann.de)
- get acid-free carton and cardboard from Oekopack Conservus AG (Spiez CH, www.oekopack.ch) or Tschudi + Cie AG (Netstal CH, www.tschudi.com)
- get polyethylene foil tubes from Kopp Verpackungssysteme (Reichenbach DE, www.kopp-online.de/images/download/produkt_pdf/pe_folie_d.pdf)
- get plastic bags from Hans Schröder GmbH (Karlsdorf-Neuthard DE, https://archivbox.com/en/archiving-photographies/pages-pockets-envelopes/bags/?nbnet=1#) or the Plastik Haus AG (Arlesheim CH, www.plastic-haus.ch) or Semadeni AG (Ostermundigen CH, www.semadeni.ch)
- get Tyvek® Soft Non-Woven 1623 E from Deffner and Johann
- get OSTEO-FIX from Bauer Handels GmbH (Fehraltorf CH, www.taxidermy.ch)
- get Paraloid B72 dissolved in ethyl acetate, 15% from Kremer Pigmente (Aichstetten DE, www.kremer-pigmente.com)

Further reading

- for labelling details and the use of Paraloid B72, see PrevArt (2014)

2.8 Geosciences

The witnesses of the past preserved in geoscientific collections include remains of former life forms (anthropology and paleontology), natural minerals and synthetic substances (mineralogy), extra-terrestrial material (meteorites) and various types of hard rocks (petrography). While hard rocks can often be stored relatively easily, meteorites, minerals and fossils are often more demanding: fragile parts must be protected and their special properties taken into account. Certain samples contain or consist of unstable components, are toxic or may represent other health risks.

Examples

- for a brief overview and introduction to geoscientific collections, see the webpages of the Technische Universität Bergakademie Freiberg (TU Freiberg 2020) or of the department Geowissenschaften at the NMB in Basel

2.8.1 Hard rocks

Hard rocks without toxic, harmful or unstable mineral components can be stored relatively easily in rooms without special conditioning. The rooms should be dry (< 60% relative humidity), closed and designed to withstand the weight of large and heavy objects. For easy handling with a pallet trolley or pallet lifting truck, large, heavy stones are ideally stored on wooden pallets directly on or near the floor. Smaller stones can be stored together with their labels in suitable open boxes in drawers or on sufficiently strong trays. Hard rocks with unstable, toxic or health-endangering components require special treatment, depending on the substances they contain.

2.8.2 Meteorites

Meteorites are solid objects from space that fall onto planetary bodies. They are fragments of other bodies from our solar system, mostly derived from asteroids, while a small fraction represents fragments of the moon and of the planet Mars. It is a common misconception that meteorites should contain unusual components or even elements unknown on earth. Meteorites, the earth and all rocky bodies of the solar system were formed from the same cloud of dust and gas and are therefore quite similar in their chemical composition and mineralogy, yet still exhibit a series of unique characteristics.

Meteorites can contain iron and salts, and they are therefore susceptible to humidity. In addition to controlling the humidity of the air, temperatures should remain constant to prevent condensation of water on their surfaces. To keep meteorites as pristine as possible, the use of gloves for any handling and storage in rooms with low humidity (< 40% relative humidity) is recommended. In different museums worldwide, that possess large meteorite collections, storage systems range from high-purity nitrogen cabinets to no special systems at all.

Utmost care should be applied in the case of freshly fallen meteorites. If trace organic compounds are to be analysed, contamination with terrestrial organic compounds should be prevented. Also, freshly recovered meteorite specimens should not be handled with magnets.

Recommendations

→ keep meteorites dry and at constant temperature
→ inspect specimens regularly for signs of rust

Figure 2.8.2.a: Bulk storage of meteorites from one strewn field in wooden drawers at the at the NMBE in Bern. For single meteorites this storage method is not appropriate (photo Lisa Schäublin)

2.8.3 Minerals

The handling and storage of minerals is the same as the handling of fossils. They should be stored in dry rooms where there is a constant relative humidity of 45–55%, with as little fluctuation as possible. With the exception of highly radioactive minerals, minerals do not require storage in a separate room but can be stored together with fossils. For health reasons, toxic or harmful minerals are best kept in closed containers and labelled as such. Asbestos in particular is ideally kept in closed boxes (Horak et al. 2016). See also section 3.7.1.

Storing minerals in boxes

Minerals are usually stored in acid-free boxes of suitable sizes (see figure 2.8.3.b). Pointed, fine and delicate minerals are best stored in closed containers, thus reducing the chances of damage during handling. In case of very delicate objects, the insides of containers can be padded. To prevent the loss of single crystals, individual small, fine crystals may be kept in acid-free or clear plastic boxes (with lids) of an appropriate size (see figure 2.8.3.a). Some minerals absorb water and are very sensitive to humidity in the air. These minerals are best stored in closed, airtight containers. For safety and monitoring, silica gel that changes colour at high humidity can be added to absorb excess moisture. The storage and conservation of sensitive minerals such as pyrite are covered in section 2.8.4.

Gemstones

Storage conditions for gemstones and other precious stones are identical to other minerals but special safekeeping is advisable due to their value. They are usually stored in acid-free boxes, ideally closed. Specially crafted transparent plastic boxes with foam or cotton lining exist for gems. The lining should be thick enough so that when the box is closed, the gem is pressed against the lid and thus cannot move.

Radioactive specimens

Depending on their composition, radioactive minerals and ores can emit relatively strong ionising radiation. Since this cannot be perceived directly by humans and is harmful to human health at certain levels, 'all measures dictated by experience and the current state of science and technology must be adopted in order to limit the radiation exposure of each individual person and of all parties' (RPA 814.50, Art. 9, see also section 3.7.1). All concerned persons must be informed about radioactivity in collections, from cleaning staff to technical service staff and the fire brigade, to ensure an appropriate response in emergency situations. According to the Radiological Protection Act (RPA 814.50), the handling of radioactive substances is subject to authorisation. The Federal Council, however, may provide exceptions for substances with low radioactivity. In geological collections holding radioactive minerals, an evaluation by a licensed expert is required to comply with radiation protection regulations (RPA 814.50). Regular monitoring of radiation emissions by a recognised agency is recommended. According to the Radiological Protection Ordinance (RPO 814.501), the license holder must ensure that only authorised persons have access to radioactive materials and that the radiation exposure limit of 1mSv/y is observed (StSV 814.501, Art. 22, 56–57). Apart from personal protective measures such as minimum length of stay, maximum distance from the source of radiation and working with protective equipment, labelling and placement of the minerals are also important in radiation protection. Radioactive minerals are best kept in closed containers to prevent absorption of small particles by inhalation, skin contact or swallowing. Ideally, all such objects should be stored together in a locker specifically designed and clearly marked for this purpose. Besides radioactive minerals and ores, fossilised bones, teeth and wood can contain high levels of radioactive minerals (Price et al. 2013). In many cases, this may go unnoticed until the ionising radiation is measured. Price et al. (2013) provided guidelines on how to identify radioactive mineral contents, how to determine who may be at risk due to specimen handling and how to monitor and minimise exposure according to health regulations.

Figure 2.8.3.a: Polystyrene boxes to store minerals in the MHNF in Fribourg (photo Michael Maillard)

Figure 2.8.3.b: Plastic boxes for large geological specimens in the MHNF in Fribourg (photo Michael Maillard)

In particular for gaseous decay products such as radon, effective ventilation can significantly reduce health hazards.

Recommendations

→ mark harmful, radioactive and toxic minerals with a label
→ comply with radiation protection regulations

Examples
- acid-free cardboard boxes of different sizes and small plastic containers with upholstery foam are used in the NMB in Basel
- folded, acid-free cardboard boxes to store smaller stones and minerals are used in the NML in Luzern

Suppliers
- get small plastic containers from Semadeni AG (Ostermundigen CH, www.semadeni.com) or Brac-Werke AG (Breitenbach CH, www.brac.ch)
- get upolstery foam from Medewo AG (Meisterschwanden CH, www.medewo.ch)
- get acid-free carboard boxes of different sizes from Tschudi + Cie AG (Netstal CH, www.tschudi.com)
- get foldable acid-free carboard boxes from Oekopack Conservus AG (Spiez CH, www.oekopack.ch)
- get plastic boxes for gems from Mineralienkontor Dr. F. Krantz (Bonn DE, www.krantz-online.de)

Further reading
- for information on identifying and managing radioactive geological specimens, see Price et al. (2013)
- for identifying and managing asbestiform minerals in geological collections, see Horak et al. (2016)
- Radiological Protection Act (RPA)
- Radiological Protection Ordinance (RPO 814.50)

2.8.4 Fossils

Fossils can be completely petrified, include original material or organic matter, contain unstable mineral parts or belong to the so-called subfossils consisting mostly of original material. The latter often do not differ significantly from zoological objects and can usually be stored in the same way (see section 2.7). Completely petrified fossils are the least problematic and may be stored relatively easily under standard conditions, like simple hard rock specimens and most other stable minerals. Fossils with unstable components may require special rooms or storage conditions.

Small, fragile fossils may need to be stored in closed containers, boxes, or glass vials to prevent specimens and labels from getting lost. Even in smaller fossils, the application of accession numbers directly onto the specimen can prevent misplacement if several containers or storage boxes are opened for comparative studies or for inventory purposes (see figure 2.8.4.a).

Pyritised fossils are unstable

Pyritised fossils, containing the iron sulphides pyrite or marcasite, are unstable and prone to decay under normal atmospheric conditions, a process known as 'pyrite-marcasite destabilisation' or 'pyrite disease' (Larkin 2011). The combination of high relative humidity and atmospheric oxygen causes a reaction producing sulphuric acid that attacks affected specimens and which may also affect nearby drawers, labels, boxes and other neighbouring fossils. If stored in glass, affected specimens can expand and shatter their containers. Decay can be prevented if specimens are stored in an oxygen-free environment, i.e. in an inert gas compartment. For larger specimens or whole collections, however, this may not be feasible, given the costs associated with airtight storage cases or other such storage options. According to Larkin (2011), the neutralisation of sulphuric acid may be achieved through treatment with ammonium gas or ethanolamine thioglycolate.

Important prevention measures include the identification and isolation of potentially affected pyritised fossils, a relative humidity between 30–45% if possible but certainly below 60% and regular collection checks to detect the beginnings of pyrite decay, such as the presence of greyish-yellow dust smelling of sulphur.

Oil shale fossils can easily fall apart

Oil shale fossils can fragment if the mother rock is drying out. A short-term transfer into distilled water can save the rock from dehydration. If stored for a longer time in water (not recommended but potentially necessary in certain cases), an additive should be used to prevent the growth of mould. For mid- to long-term rescue, specimens can be stored in glycerine or permanently transferred to synthetic resins. In the latter technique, known as the 'transfer method', the synthetic resin becomes the new support for the fossil and the original, fragile sediment is removed. To perform this transfer, different 2-component epoxy resins are available, some of which are also transparent, such as Araldite, Biresin and Bakelite/Epikote. Embedding the fossil is a permanent measure. The application of transparent or non-transparent resin should therefore be carefully considered prior to the start of preparation, and depends on the following questions: which side should be visible at the end? Should the backside of the fossil be still visible through the resin? Shall the specimen be displayed in the future? Will indirect lighting of the fossil through the resin be used?

Figure 2.8.4.a: Ammonites at the NMSO in Solothurn (photo Thomas Briner)

Fossilised proboscidean tusks and teeth

When removed from sediment, larger mammoth or other proboscidean tusks and teeth may dry out and become brittle, requiring stabilisation. The dentine of the teeth and tusks may prove difficult to stabilise and continued disintegration is a risk. Especially molars or tusks removed by dredging from the North Sea floor may require additional watering and repeated rinsing in freshwater to remove salt content prior to consolidation. To fill pores and larger cracks for stabilisation, a mixture of Paraloid B72 in varying solutions of acetone is applied (e.g. Carrió and Da Rocha 2014). The specificities of the solution depend on the required viscosity of the solvent.

Fossils in amber

Amber is sensitive to exposure to light, fluctuations in humidity and temperature and oxidation. Damage can take the form of 'crazing', in which fine cracks form close to the surface of the amber. If such cracks remain superficial, and if the inclusions in the piece are not too close to the surface, cracks may be removed by re-polishing the surface of the piece. More severe damage includes deep cracking, which is irreparable and compromises the integrity of the piece and any inclusions within (Bisulca et al. 2012). Different types of amber respond differently to external factors such as light, temperature and humidity but some basic storage conditions can be highlighted. Amber should be protected from exposure to light by keeping pieces in closed containers. Relative humidity should be kept stable, although recommended values vary between 35–45% (Bisulca et al. 2012) and 55% (Trusted 1986, Leiggi and May 2005). The ambient temperature should also be kept stable, ideally between 16° C and 20° C (Shashoua 2002, Bisulca et al. 2012). Furthermore, active chemicals such as ethanol or acids may dissolve amber and the presence of mineral oils can be detrimental in case of long-term exposure. If there is a need to place the piece in a liquid medium, for instance to cancel surface reflections for photography, the specimen can be placed in glycerol.

Amber darkens when exposed to oxygen, which is an irreversible process, accelerated by exposure to ultraviolet light and dry air. The oxidation takes place at the surface of the amber but will also invade the piece through cracks. Eventually, long-term exposure may darken the piece to such a degree that study of the inclusions by light microscopy may become virtually impossible. Polishing can remove the dark layer obscuring the inclusion but if ambient conditions remain the same, the darkening process will begin again and at some point, further polishing will become impossible without damaging the inclusion. A more viable long-term solution is to store the amber in a way that slows down the oxidation process as much as possible. An ideal solution, albeit expensive and impractical, is to store the amber in an inert gas, such as argon.

Figure 2.8.4.b: Ant in amber at the MHNG in Geneva (photo Philippe Wagneur)

A more viable method is to embed the specimens in an artificial resin, like epoxy. A compromise is to store amber pieces individually in zip-lock plastic bags to minimise exposure to atmospheric air and to wrap old labels separately to prevent contact between the acidic paper and the amber itself.

Finally, several more recently developed techniques, such as microCT and confocal laser scanning, have the potential to revolutionise the study of amber. These non-invasive scanning techniques not only allow observation of internal features (if preserved) of inclusions but can also negate certain effects, such as darkening, occlusions and cracks, that might impede observation of inclusions with normal light microscopy.

Recommendations

→ store oil shale fossils in glycerine or, in the case of most vertebrate fossils, on 2-component epoxy resins using the transfer method
→ store pyrite fossils in areas with low relative humidity; affected specimens can be treated and then stored in oxygen free, i.e. inert environments
→ to store amber, avoid UV light, and fluctuations in heat and humidity
→ avoid contact between amber and acidic materials and minimise exposure to oxygen

Examples

- a large oil shale fossil slab with a decaying crinoid was treated as mentioned above and is now stored at the Werkforum und Fossilienmuseum by Holcim AG in Dotternhausen DE (Mallison 2011)
- extensive renovations were done by the Museum of Geology and Palaeontology of Padova University to preserve their 'Hall of Palms' (see Becherini et al. 2018)
- transferring the oil shell fossils to epoxy resin slabs is necessary in most fossils (e.g. vertebrate skeletons) from the UNESCO world heritage 'Messel Pit Fossil Site' near Darmstadt, Germany. Plant remains were usually stored in glycerine but the Hessisches Landesmuseum Darmstadt is currently experimenting with storing plant fossils from the Messel pit in silicone oils

Suppliers

- Araldite is sold by HUNTSMAN (www.huntsman.com). A current Swiss provider is Bodo Möller Chemie Schweiz AG (Winterthur CH, https://bm-chemie.com)
- Bakelite was taken over by Hexion (www.hexion.com), with one of their low viscosity epoxy resins options being EPIKOTE™ Resin 320 with EPIKURE™ Curing Agent 161. This epoxy resin can be bought from Suter Kunststoffe AG (Fraubrunnen CH, www.swiss-composite.ch)
- get Paraloid B72 pellets that can be dissolved in acetone from e.g. Art-Restore (Nänikon CH, https://art-restore.ch), Haufwerk (Jena DE, www.haufwerk.com) or Carl Roth Laborbedarf (Arlesheim CH, www.carlroth.com/ch)

Further reading

- for methods of neutralising sulfuric acid, see Larkin (2011) and Becherini et al. (2018)
- for the treatment of pyritised fossils, see Weick (2011) and Weick-Neher (2012)
- for a whole issue dedicated to oxygen-free museum cases, see Maekawa (1998)
- for a fast preparation guideline for oil shell fossils (transfer method), see Kaiser and Micklich (1995)
- for an introduction to the conservation of amber, see Thickett et al. (1995), NPS (2011) or Vincent et al. (2012)
- for the preparation of amber fossils, see Green (2001)

2.8.5 Soil

Soil samples are damp and rich in organic matter. Storage is difficult but can be done by freezing or drying (Ayres 2019, Kühnel et al. 2019). Soil is most often preserved as a monolith, which is a repacked soil column stored in a long open box and treated with resin (van Baren and Bomer 1979). The process of creating a monolith begins in the field while collecting (Allaire and Bochove 2006).

Example

- for instructions on how to make a soil monolith, see https://serc.carleton.edu/introgeo/field_lab/examples/soil_monolith.html

Further reading

- for quantitative guidelines for establishing and operating soil archives, see Ayres (2019)

2.8.6 Drilling samples

Drill samples consist of cores of hard rock or crushed rock debris (cuttings). They often contain raw material minerals. Solid rock cores without problematic materials can be stored like hard rock. Loose stone cores require a container, which is usually made of wood cut in meter pieces. Depending on the nature of the raw material components, different conservation measures are required (e.g. for water-soluble substances, unstable minerals, etc.). Oil samples from wells are usually kept in closed glass containers.

Preparing and storing well cores

Well samples arriving from a rig are usually very damp. Unless pollen is to be extracted, they need to be dried before they are stored. For cuttings, this can be done at low temperature in an oven. To avoid adding extra humidity to samples, long cores are dried in a temporary storage room. Furthermore, disinfection may be necessary in order to avoid the proliferation of bacteria. Well cores are stored in long boxes not exceeding 80 or 120 cm in length, so they can fit on a standard palett and be handled by a single person (see figure 2.8.6.a). Boxes can be wooden or metallic, ideally with no lid, so that the content can be seen easily. They can also be fitted in a PVC tube cut in half. Important information such as borehole name and depths should be written both on the box and the core. Polarity indications

Figure 2.8.6.a: Well cores are stored in a solid box labelled with the essential information deposited at the NAGRA in Mellingen (photo Robin Marchant)

are also important to know the orientation of the core (top and bottom). These long boxes can be stored on palettes or on solid shelves. A single well can produce a considerable quantity of samples, be they cores or cuttings. Down-sampling may be necessary if storage facilities are limited. For this, two methods may be used: regular down sampling, for instance by taking a 10 cm core sample every meter, or by selection of particular specimen properties, such as the top and bottom of each formation, or other representative and peculiar features.

Cuttings should be washed of the drilling mud to prevent rock debris from cementing together and, if necessary, disinfected. Since plastic or cloth bags tend to disintegrate over time, they are stored in closed polystyrene boxes or other small containers. After labelling each sample, they are stored in solid drawers or in euro-pack boxes on a palett or on solid shelves.

Recommendations

- → dry samples and disinfect them, if necessary, before storing
- → down-sample the specimens in case of limited storage
- → label samples and containers

Supplier

- get polystyrene boxes from Semadeni AG (Ostermundigen CH, www.semadeni.com)

Further reading

- for preparation and storage of drill cores and cuttings, see NPS (2010) and the Geological sample submission procedure by the Northern Territory Government (2020)

2.9 Special collections

Some collections need special treatment independent of their taxonomic group, such as microslides or when conserving tissue samples for DNA analyses. Others are stored separately from the scientific collections due to frequent use, such as didactic collections. And some, like scientific drawings and paintings, require special storage conditions that differ from the standards found in most natural history collections.

Figure 2.9.1.a: Storing protozoan microslides in the collections of the MHNG in Geneva (photo Philippe Wagneur)

2.9.1 Microslides

Microslides are relatively easy to store and may be kept at room temperature under normal conditions. Slides should be handled gently, kept in the dark and at cool temperatures, and stored on stable shelving, especially in the case of large and heavy slide collections (Carter and Walker 1999). Permanent mounts are best prepared with resin-based products, such as Canada balsam and Euparal for botanical and mycological specimens, (Carter and Walker 1999) and epoxy resins for fossils. As slide mounts will always remain fluid to some extent, they should be stored flat with the mount on the upper side. Slotted slide boxes, for instance, should be stored upright like books on a shelf and marked in a way that indicates how to open the box correctly, to prevent slides from falling out and breaking. Microslides may be stored together with the main collection or separately with other microslides.

Fossil microslides

In fossils, the size of the microslide should correspond to the nature of the fossil, whether it be a longitudinal or tangential cut or a cross section, a small or large fossil, or a cross-drilling sample from a large fossil (e.g. Chinsamy and Raath 1992, Stein and Sander 2009). Commonly used microscope slides for fossils, also referred to as palaeohistological slides, come in different sizes: common formats are 2.5 × 5 cm, 5 × 5 cm, 7.5 x 5 cm. Unusual formats may include anything up to self-cut window panes measuring tens of centimetres in length and width. Palaeohistological slides are usually thicker than standard microscopy slides used in biology labs. They can be up to several millimetres thick, partly to withstand strains on the slide that might occur during the preparation of the fossilised samples. Due to the wide range of sizes and thicknesses, palaeohistological slides are stored in a variety of different slide boxes.

Labels for microslides

Care must be taken with slide labels. Some commercially available slide labels are unsuitable for permanent preparations because of the poor quality of the paper or glue. If a self-adhesive label is used, ensure that it is of archival quality (with acid-free adhesives) (Carter and Walker 1999).

Recommendations

→ standardise storage types if possible
→ use resin-based mounting for long-term storage, i.e. Canada balsam and Euparal in botanical and mycological preparations, and epoxy resins in fossil preparations

Examples

- to see one of the largest collections of palaeohistological slides in Switzerland, visit the PIM in Zürich

- to see preserved microscopic algae (diatoms) on microslides and stored in histologic preparation boxes, see the MHNG in Geneva
- for taxonomic studies, the type specimens represented in the cryptogamic collection of the CJBG in Geneva have been removed from the general collection and stored in separate fire-proof metal cabinets (Clerc et al. 2017)

Supplier

- storage boxes can be bought from a broad range of histology lab suppliers like Carl Roth Laborbedarf (Arlesheim CH, www.carlroth.com/ch)

Further reading

- for an extensive overview of storing, managing, and digitising slide collections see Neuhaus et al. (2017)

2.9.2 Scientific drawings and paintings

The conservation of drawings and paintings is a vast topic and the text herein can only touch on this theme to a limited extent. Pencils, charcoal, ink and watercolours are very resistant to aging but a loss of colour over time is still unavoidable. Drawings suffer from external factors, such as UV light exposure, high humidity, pests, and pollution, as well as from internal factors, such as poor paper quality. While external factors can be more or less controlled, internal factors are difficult to cope with. If the paper is of poor quality, as is the case with documents from the period 1830–1990, chemical degradation is virtually unavoidable. Usually, they can only be remedied with much effort and cost.

Drawings should be stored in acid-free silk paper inlays, lying in a metal flat file cabinet in a dark room. If there is light, the intensity should be as low as possible (maximum 50 lux). Optimal climatic conditions are 18°C and 45–55% relative humidity (according to the Staatsarchiv des Kantons Aargau). Pests are most likely to enter the collection with objects from private donations and special caution is required when integrating them. Thorough disinfestation and temporary storage in a separate quarantine room are helpful. Pest infestations can be treated by deep-freezing the material at –18°C for one week in airtight bags, which are only opened after the material has reached room temperature again to prevent condensation. Mould damage is a difficult problem and usually requires assistance from a specialist.

Recommendations

→ store material at 45–55% relative humidity and in the dark
→ prevent pest damage by regular controls and quarantine of incoming material
→ see also section 2.4 on storage materials, and section 2.6.1 on herbarium sheets for further information

Suppliers

- information and specialists on cultural heritage from SKR – Schweizerischer Verband für Konservierung und Restaurierung (https://restaurierung.swiss)
- get pest prevention services from Desinfecta AG (Deisswil bei Stettlen CH, www.desinfecta.ch)

Figure 2.9.2.a: One out of several hundred water colour paintings from around the turn of the 19th century of the Gottfried Keller collection at the NAAG in Aarau (photo Matthias Nöske)

- get archival quality material, like acid-free paper ISO 9706, from Oekopack Conservus AG (Spiez CH, www.oekopack.ch)
- get metal cabinets from Lista AG (Erlen CH, www.lista.com)

Further reading
- for detailed information on the storage of culture heritage objects, see Huber and von Lerber (2003) or Hilbert (2002)
- for prevention of health risks and damage on objects by mould, see BAUA (2010) and BKK (2010)

2.9.3 Didactic collections

Many museums hold collections of specimens of no scientific value, which are used for didactic purposes and loaned to schools or other educational institutions. These specimens may have either incomplete or lacking data, or represent an excess of duplicate specimens from the main collection (see figure 2.9.3.a). Because of their limited value, they are handled differently from the rest of the collection. First, the loaning policy is relaxed for these specimens and the risk of damage or even total loss is accepted. Second, to allow for frequent borrowing by different users, quarantine for returning specimens from didactic collections is not done rigorously, but at arbitrary intervals, for example once a year. Instead, a quarantine cupboard or a quarantine room may be helpful for observing potential pest infestations during a certain period before returning the object back to the didactic collection. With regard to integrated pest management, didactic collections are stored separate from the scientific collections (i.e. in another room) to prevent contamination of the main collection with pest specimens introduced by returning loans.

Arsenic content should be evaluated for each specimen and those exhibiting high levels must be removed from the didactic collection. Objects at levels below 1,000 ppm/kg can still be loaned, if labelled correctly. Giving borrowers clear instructions on the handling and storage of loaned specimens will help minimise exposure of users and also prevent damage and loss of the specimens. Instructions can be published on websites, loan forms, or given personally when handing over the loan.

To minimise damage, the following measures might be considered. Vertebrates can be easily fixed for transport on a robust tray of plastic or wood, lined with a styrofoam board. Covering the tray with a lid is not advisable. Skulls are best transported in bubble wrap envelopes. Bases with acrylic glass hoods protect full mounts from dust and other impacts as well as being less attractive for pests. Objects like assembled skeletons of amphibians or reptiles can be stored and exhibited attractively in insect boxes. Other objects may be packed and stored in trays with lids. Clear lids will offer a full view of the packaged product during transport and increase the probability of appropriate handling.

Recommendations

→ inform borrowers about correct storage and handling of loans

→ measure concentrations of biocides prior to loaning specimens

Suppliers
- for an x-ray fluorescence spectrometer (XRF) to measure arsenic and mercury contents contact the NMBE in Bern or Sarah Idargo (Hochschule der Künste Bern)
- get bubble wrap envelopes from Plastic Haus AG (Arlesheim CH, https://plastic-haus.ch)
- Acrylic glass hoods are available from Semadeni AG (Ostermundigen CH, www.semadeni.com) or from Bauer Handels GmbH (Fehraltorf CH, www.taxidermy.ch)
- Transparent lids and bases are available from Staeger and Co. AG (Muri CH, www.staeger.eu/en/products/transparent-packaging/lids-bases)

Further reading
- for information on the safe handling of specimens treated with arsenic, see Chemsuisse (2019)
- for information on setting up a loan contract in German, French and Italian, see Burnand and Demierre (2012)

2.9.4 DNA and tissue samples

In dead tissue, enzymatic activity and oxidation lead to damage and degradation of nucleic acids (Nagy 2010). Since these enzymes need water to be active, the key to tissue preservation is the rapid and effective removal of water. Preservation in ethanol and rapid drying of the specimen are two common methods of quickly eliminating water from tissues.

Liquid preparations of insects for DNA analysis
Insects should be killed with non-denatured, 80–100% ethanol. Contact with ethyl acetate and formaldehyde must be avoided at all costs, as it makes DNA extraction impossible. The specimens are then placed intact and one by one into matching glass tubes with non-denatured, absolute ethanol, and the tube is sealed with cotton wool. Tubes are put in a suitable jar filled with non-denatured, absolute ethanol and closed tightly with a screw-top lid. Specimens are stored protected from light and at low temperatures (< –15° C). This simple procedure ensures long-term, perfect preservation of the DNA. Several other

Figure 2.9.3.a: Mollusc shells lacking data and therefore without scientific value but suitable for a didactic collection (photo Lisa Schäublin, NMBE)

methods are also used occasionally (see Carter and Walker 1999). The appropriate conservation method should be discussed with the DNA laboratory before the project starts.

Preparation of molluscs for DNA analysis

Sequencing is usually done from specimens stored in ethanol. Preparation of molluscs for DNA analysis can take several methods: in case the animal is large and/or not needed for further investigations, a tissue sample from the mantle edge or the foot is sufficient. Even a mucus smear can provide enough DNA for analysis. In case the specimen is needed for additional investigations (often in taxonomic revisions), the animals are killed with boiling water and immediately transferred to 100% ethanol. The ethanol is renewed after approximately 30 minutes (depends on the size of the specimen). After another 30 minutes, the specimen is transferred to 80% ethanol for permanent storage. Tiny to minute mollusc species (< 5 mm shell length) are best preserved as dried mummies directly after collection by immediate desiccation of the body after which they can be stored in the dry collection. Tissue samples are best stored at –20°C or even –80°C.

Recommendations

- → use pure and non-denatured ethanol for preservation
- → store specimens in freezers at –80° C and have a spare empty freezer for emergency transfers
- → use ethanol without additives (non-denatured), as many additives are known to destroy or degrade DNA
- → store the whole specimen in a plastic (not glass) tube in freezers just like in 'normal' DNA samples, if the specimen is very tiny

Supplier

- the Global Genome Biodiversity Network (GGBN) is the global reference institution to promotes access to information about and legal exchange of genomic samples

Further reading

- for an overview on tissue preservation, see Nagy (2010)

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Notes

Chapter 3: Prevention, monitoring and intervention

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3.1 Introduction

Natural history collections archive voucher specimens for future generations. Such specimens cannot be conserved forever but by following certain rules, they can be protected from biological, chemical and physical harm and their deterioration can thus be delayed.

This chapter deals with methods that aid in the conservation of natural history objects. Central themes include the conditions that should be provided to protect objects from harm (see section 3.2), the treatment of objects prior to integration into a collection (see section 3.3), identifying and detecting threats to a collection (see section 3.4), the measures that can be taken to neutralise these threats (see section 3.5), the evacuation of important objects in case of an emergency (see section 3.6) and, last but not least, the safety of collections staff (see section 3.7).

We do not intend to re-invent the wheel but rather guide collection managers to the most important information and provide them with relevant literature references for more detailed information, all the while referring to examples from Switzerland. The information given is not exhaustive but instead reflects knowledge from members of SwissCollNet working groups. We hope that this chapter will help to increase collection management quality in a simple and straightforward way by connecting information and people.

Further reading

- for a general overview on preventive conservation, see e.g. Carter and Walker (1999), Waller (2003), Waentig et al. (2014) or the online guides of MP-WG (2020), the CCI (2020) or Graham (2018)
- for integrated pest management (IPM), see Pinniger et al. (2016)
- for an overview on storage facility conditions and measures, see Huber and von Lerber (2003) or Hilbert (2002)

Figure 3.1.a: Vertebrate collection of the MHNG in Geneva (photo Philippe Wagneur)

3.2 Preventive infrastructure

Collections are stored in all types of buildings. The quality of such buildings ranges from brand new, custom built infrastructures that meet all the needs for specimen conservation, to old army arsenals, perhaps low-cost but far from representing suitable infrastructure for long term storage. In this section we discuss the requirements and possibilities for preventive infrastructures for the long-term storage of specimens. The discussion is not about the buildings themselves, which was discussed in section 2.2, but rather the measures that may be taken to create barriers to the collections and the conditions that should be maintained in the facilities, such as temperature, humidity and light.

In general, collection rooms should be sealed off from the outside world, as well as dark, well-ventilated and cool to reduce the risk of pest infestation and material damage or deterioration. The storage space should be relatively easy to clean e.g. without shelving directly attached to the walls. A clear cleaning concept must be outlined and training for the cleaning personal should include special guidance with respect to the presence of biocides (for example, dichlorodiphenyltrichloroethane [DDT], pentachlorophenol [PCP], lindane, naphthalene, mercury, arsenic) in the collection. No workplaces should be located in the collections to reduce the risk of biocide exposure.

Recommendation

→ for the planning of new storage facilities and archival conditions, get in touch with specialised companies such as PrevArt GmbH (Winterthur CH, www.prevart.ch)

Further reading

- for a general discussion on light, temperature and relative humidity in natural history collections, see e.g. Hilbert (2002) or Carter and Walker (1999)

3.2.1 Barriers to the collections

Collection infrastructure is the first line of defence for collections (Carter and Walker 1999). The collection space should be sealed off against external factors as much as possible. These include pest insects, inappropriate temperatures, relative humidity and light but also disturbances caused by people.

Sealed rooms

Sealing off collection facilities from external factors is the ideal means of stabilising conditions inside a collection space. This can be done in several ways.

If new infrastructure is built, the collection facilities can be sealed off from outer disturbances. The only connections between the collections and the outside world should be limited to the entrance door(s), the air conditioning vents, electrical installations and security measures, such as firefighting systems. This model was followed during the construction of the collection tower of Naturalis Biodiversity Centre in Leiden in the Netherlands but is also common in newly built collection facilities in Switzerland, e.g. in the Naturhistorisches Museum Bern.

Most collection holding institutions, however, have to do the best they can with what they have. In these cases, the number of windows should be limited as much as possible to protect the collection from UV light. Windows should be sealed or kept closed to prevent insects from entering the collection as well as to keep temperatures and relative humidity as stable as possible. If windows must be opened to aerate the space (i.e. if a ventilation system is absent), it is both essential and effective to cover them with insect screens in order to prevent insect pests from entering. This is especially true for collections but is also advisable in exhibitions and at work stations where collection items are present.

Some institutions have chosen to build a 'room inside a room' infrastructure (see figure 3.2.1.a). In this way, suboptimal infrastructure can be transformed into a suitable collection holding facility in which objects can be stored under controlled conditions.

Double door system

Closed rooms are ideal for collection storage but as collections need to be managed and use for research purposes, this is not always possible. The opening of doors places the collection at risk because this permits the entry of pest insects, mould spores and air of suboptimal temperatures and relative humidity into the collection. This issue can be solved with a simple double door system. Ideally, the space between the two doors should be big enough to permit the entry of several persons, if needed, at one time and

Figure 3.2.1.a: Army arsenal with built-in sealed storage facility (see roof and walls) for the bone collection and herbaria of the MHNF in Fribourg (photo Michael Maillard)

should provide enough space for the transit of trolleys to transport collection items.

The space between the double doors may be equipped with different types of traps (see section 3.4.2) to catch insects that may have entered from the outside. Such a system keeps most pest insects from entering a collection and is relatively cheap to install. If the space between the double-doors is air-conditioned, it also brings entering air closer to the optimal temperature and relative humidity for the collections before it is introduced into the main collection space.

Access for staff only?

Most collections are only accessible to collection/inventory managers, scientific staff and scientific visitors, as they are closed to the general public. However, nowadays it is more and more popular to show the public what happens behind the scenes of a museum. Some collections become parts of exhibitions, like in the Museum für Naturkunde Berlin, or soon in the newly built Naturhistorisches Museum Basel. Some natural history institutions have started to offer guided tours to show their collections to the public, such as the Naturama Aargau or the Musée de la nature du Valais in Sion.

Although such visits offer the public a wonderful opportunity to see parts of the museum that are otherwise inaccessible, they present a certain risk to the collections and it is advisable to develop protocols that visitors must follow. Guided tours should only be offered to small groups to reduce rapid increases in the relative humidity of the collection and all visitors should be kept in sight at all times. Although not yet fully assessed, intensive visits to collections during public outreach activities may represent a potential threat due to the possible introduction of pest insects. Thus, as a preventive measure, all jackets, bags, rucksacks and other non-essential items should be left outside, to avoid the accidental introduction of pests into the collection space and damage the specimens through inattention.

There is also a debate concerning who, if anyone, should work in a collection apart from those responsible for the upkeep of the collections themselves. From a collection conservation perspective, disturbance to the objects should be kept to a minimum and optimal conditions for objects are not necessarily optimal for workers. Also, according to Ordinance 3 of the labour law (ArGV 3, Art. 2b), workers must be protected from physical, chemical and biological harm. Therefore, measures must be taken to protect those working in spaces where objects may be contaminated with biocides. In such cases, working in the collection would only be possible with protective gear like a filter mask.

Recommendations

- → separate and seal off collections from external sources of physical and biological harm
- → install a double door system to keep pests out of the collection
- → keep disturbance to the objects at a minimum by isolating the collection from pests and from harmful fluctuations of temperature and relative humidity
- → offer guided tours through the collections only to small groups to reduce rapid increases in relative humidity and keep all visitors in sight. To reduce the risk of accidentally introducing pest insects, restrict tours to the winter months and ask visitors to leave bags, jackets and other personal items outside the collection
- → if integrating whole collections into exhibitions, objects should be shown in an enclosed compartment, kept under the same conditions as the other collections and separated from the public using glass
- → use synthetic delivery pallets in the collections for storing, especially if you don't have the means to treat them by oxygen deprivation (see section 3.3.3), given the potential risk they represent for the introduction of new pests
- → use wooden pallets only if you plan to do a treatment by oxygen deprivation prior to their introduction into the collections. A treatment is only possible with a fast air exchange

Examples

- double door systems are installed in many collections, such as the ETHZ-ENT in Zürich and the NAAG in Aarau
- a sealed room for collections storage was built inside the old military arsenal used for storing objects by the MHNF in Fribourg
- a deep-freezing facility was installed between the two doors at the NAAG in Aarau (see section 3.3.1 for procedure and for delicate specimens see section 3.3.3). All objects entering or returning the collection are first deep frozen before integration into the completely sealed (wooden boards with silicone joints) storage facility
- despite being separated from the work spaces, most institutions have their collections as close as possible to the workers, i.e. in the same building, as at the NMSG in St. Gallen or even on the same floor, as in e.g. the MNVS in Sion

Suppliers

- for the planning of new storage facilities and appropriate storage conditions, get in touch with specialised companies such as PrevArt GmbH (Winterthur CH, www.prevart.ch)
- for UV traps, and pheromone traps, see Desinfecta AG (Deisswil bei Stettlen CH, www.desinfecta.ch)

3.2.2 Light

Light (natural and artificial) should be minimised in collections and UV light should be entirely excluded. Collections spaces should not have windows and artificial lighting should be switched off when the collection is not in use (Carter and Walker 1999).

Direct exposure to sunlight should be absolutely avoided as it causes damage to collections as well as the fixtures. In particular, pigments in flowers, feathers and fur can be altered or completely degraded due to light exposure. Direct sunlight entering collections may also bring additional climate control problems as it may increase the temperature of the room.

Museum lighting rules

Traditional museum lighting rules, as contained in various publications from the 1970s and 1980s, proposed a threshold of 50 lux, which in theory still allows workers to see all colours (Michalski 2018). Different levels were proposed from 50–300 lux, i.e. 50 lux for very sensitive

Figure 3.2.1.b: Storage of vertebrates in the NMSO in Solothurn (photo Thomas Briner)

objects like feathers and 300 lux for less sensitive ones, such as rocks. If keeping objects with different sensitivities in the same compartment, the most sensitive object dictates the maximum intensity of exposure (Michalski 2018, MGC 1992).

The rule for UV exposure was to keep levels below 75 µW/lm (the value emitted by ordinary incandescent lamps). Experience indicated that these levels provoked little to no damage to historical, mixed-object collections over many decades, given their low-light intensities. When talking about damage caused by light, it is important to keep in mind that the cumulative effect of exposure through time is more relevant than brightness at a given moment (Carter and Walker 1999).

Planning light in a herbarium

In the case of herbaria, light can be detrimental to specimens, especially if UV content is high, as is the case with sunlight. Most modern lighting systems emit a spectrum of light that is depleted in both UV and other wavelengths associated with thermal radiation. With respect to storage facilities, lighting must be carefully planned if using a movable compactor system, in order to avoid unnecessary lighting of the tops of the compactor units and a lack of light in the open space between the two compactor units that have just been opened (see figure 3.2.2.a). A complicated solution would be to have one lighting system over each space that opens between the compactor units (placed directly on the moving shelf or on the ceiling) that automatically switches on or off when the compactor unit is opened or closed. A more practical solution is to have 2–3 lines of fluorescent tubes perpendicular to the shelves, with a series of presence detectors.

Figure 3.2.2.a: Lighting a movable compactor system in the herbarium of the CJBG in Geneva (photo CJBG)

Collections with windows

If a collection room has windows they should be covered with anti-insect mesh, ideally they should be oriented northwards and have automatic shutters or be blacked-out. Otherwise, a UV protective foil should be attached to the windows, allowing light into the collection rooms but filtering out the aggressive UV light (Hilbert 2002). The foil has to be regularly checked, as it can lose its protective properties with age (usually after 10–12 years) or if cleaned with unsuitable cleaning agents (Waller 2020). UV protective varnish, however, is not recommended, as it is very sensitive to external influences and easily loses its protective properties.

Recommendations

- → keep natural (UV) light away from collection objects
- → keep exposure to all light sources as low as possible
- → install a lighting system with no UV light emission and that turns off automatically to avoid leaving the light on for extended periods by mistake
- → store objects in facilities without windows
- → if a collection room has windows, black the windows out or use UV protecting foils to cover them
- → store objects in racks/boxes that protect them from UV light

Example

- the entire lighting system in the collection rooms was replaced with LEDs in the BNM in Chur. In addition to emitting low levels of UV light, the lamps hardly heat up at all, which is an advantage in cooled rooms

Further reading

- for a summary on the deleterious effects of light, see Michalski (2018)
- for light intensity thresholds that are acceptable for different types of objects, see MGC (1992)

3.2.3 Temperature and relative humidity

Temperature and relative humidity are the main physical factors that cause objects to deteriorate. Regulation of temperature and relative humidity is a complex process and ultimately a cooling system may be the only way to regulate them. Although regarded as energy-demanding and expensive, installing an automated air-conditioning system to control both temperature and relative humidity remains the best option for long-term conservation of specimens.

Temperature and relative humidity are highly correlated and should be considered together. As a rule of thumb, relative humidity changes by 5% every 1.5°C within a temperature range of 15–25°C, assuming stable absolute humidity (Huber 2017). It is essential to keep both within an optimal range over the course of the year.

Optimal temperature for conservation

In general, as temperatures drop, materials age less rapidly, insect activity is lower and the air absorbs less moisture. However, if temperatures are too low, problems arise when working with specimens from the collection in warmer offices, as condensation can form when objects are moved (Carter and Walker 1999). As cold air absorbs less moisture than warm air, the dew point is reached more quickly in cold air and condensation forms. This explains why the risk of mould is higher in cool rooms. In the past, the temperature recommendation for collection facilities was traditionally around 20°C. However, this recommendation prioritised the comfort of workers over the conservation of objects (Huber 2017).

At the present moment, it is widely agreed that the ideal temperature range for the storage of most natural history objects is between 13°C and 15°C (Mathias 1994). This said, the optimal temperature and relative humidity may differ depending on the type of collection, especially between organic and inorganic specimens (Carter and Walker 1999).

Low temperatures prevent pest reproduction

For all collections that are sensitive to damage caused by pest insects, such as botanical, entomological and vertebrate collections, the temperatures should be maintained at 13–15°C. Temperature fluctuations should not exceed 2–3°C per day and should not take place over prolonged time periods. To prevent reproduction of most pest insects, temperatures should not exceed 16°C. However, maintaining such temperatures is very costly and temperatures up to 17°C are still adequate and considerably less expensive in the long run. Pest insects thrive between 22°C and 25°C and a relative humidity above 60%. Under any circumstances, these conditions should be avoided. Temperatures above 22°C should only be reached for 5–10% of the year, i.e. 18–36 days per year (Mathias 1994). Such temperatures have a negative influence on the relative humidity and increase the rate of damaging biological activity and other chemical reactions that take place within the specimens themselves.

Some European herbaria that hold extremely important historical or scientific collections store them in a special room where temperatures are maintained between 16–17°C. Still, a large number of European herbaria maintain temperatures ranging from 18°C to 21°C. These temperatures are adequate for the storage of herbarium specimens and optimal for the technical staff, but are sub-optimal concerning reproduction of pest insects. However, if collection temperatures can be maintained below 20°C, pest insects will be forced into conditions that are sub-optimal for their development and reproduction (Petrak 2020).

Figure 3.2.3.a: Azurite (non-scientific accession) from the NMBE in Bern (photo Lisa Schäublin)

Compromises for inorganic materials

Inorganic materials and other objects that are not likely to be infested by biological pests can be stored at moderate temperatures of 22°C. A maximum temperature range of 15–27°C within one year is acceptable for objects exhibiting a low risk of mechanical damage (Huber 2017). Whenever possible, however, lower storage temperatures are still recommended for these types of objects.

What is relative humidity?

When talking about humidity, the key factor for object conservation is not the absolute humidity but the relative humidity (RH). Relative humidity is a ratio comparing the actual humidity in the air to the maximum humidity possible, at a given temperature and atmospheric pressure. For most natural history objects, a relative humidity range of 45–55% is ideal. Carter and Walker (1999) also add that 'a dry environment is preferable to a humid one and a major concern is to maintain relative humidity levels below 60–65%, above which there are likely to be problems of mould growth. On the other hand, low relative humidity (below 30%) may cause shrinkage and embrittlement of specimens and adhesives. […] The worst problems are caused by extreme fluctuations in relative humidity, which can cause considerable damage to specimens, for example cracked skins, tusks and horns'.

Optimal relative humidity for conservation

Organic materials may be damaged by sub-optimal relative humidity in the form of dampness, dryness or significant fluctuations (Graham 2018). Huber (2017) discusses the pros and cons of different levels of relative humidity at great length, concluding that the ideal is a range of 45–55% (Huber 2017). The maximum range of relative humidity over the year should be 40–60% and the upper limit should only be reached about 5–10% of the time, i.e. in 18–36 days per year.

Perhaps most importantly, relative humidity should remain as stable as possible. Fluctuations can cause tears or cracks in sensitive materials, such as certain plants, bones, ivory or teeth (see figure 3.2.3.b, Graham 2018).

Low relative humidity hinders mould growth

Relative humidity above 60% increases the risk of mould formation; above 70%, the risk of mould infestation is very high. During the course of a day, the relative humidity should not fluctuate by more than 5%. Moulds thrive under conditions between 25°C and 35°C, especially if the relative humidity is over 60% (Petrak 2020). If relative humidity is lower, conditions are stable and air circulation is sufficient, mould growth can be prevented (Petrak 2020). Although it is impossible to keep spores out of collection facilities and off specimens, mould growth can be prevented if environmental conditions are properly controlled.

Von Lerber (2016) summarises the probability of mould infestation with increasing relative humidity: 'at 60% relative humidity, it takes about a year for mould to break out, at 70% between one and six months, at 75% four weeks to three months, and at 80% a few days to one month. This means that a short-term increase in relative humidity to 75% should not be a major problem if it is followed by complete drying out.'

However, under conditions of very low relative humidity, i.e. below 30%, skins of mammals, birds, reptiles, fish and other types of fragile taxa become brittle and therefore more vulnerable to physical damage (Graham 2018). Bones and especially teeth become brittle and break at below 45% relative humidity.

Keep the collection well ventilated

Ventilation is very important in collections. Ideally it should be a fully automated air-conditioning process. To save costs, good systems work with conditioned fresh air.

Figure 3.2.3.b: Subfossil orca skull from the early 20th century with cracks in the teeth in the collection of the NAAG in Aarau (photo Holger Frick)

For example, if it is dry outside, ventilation is set so that the air does not have to be dehumidified. If it is humid outside, the system switches to internal recirculation and reduces the proportion of outside air introduced. Ideally, the air in the room is conditioned, filtered and changed 1–2 times per 24 hours. Advantages are that the specimens can be kept at optimal stable conditions and that the concentration of oxygen in the room can be kept at stable levels for workers who are handling the collections.

Some of the poisons (biocides) that were historically used to treat collections against pests and are still present in them can evaporate and reach dangerous levels for users if air in the collection rooms is not ventilated. Briggs et al. (1983) demonstrated that by increasing the ventilation in herbarium collections, the concentration of mercury vapour in the air was reduced to safer levels.

It should be emphasised that the presence of filters is essential in the incoming air circuit, in order to avoid the entry of undesired pests from the outside. It is also of great importance that collection spaces are under slight positive pressure. In this way, air is expelled from the room any time a communication door is open, thus ensuring that pests or other contaminants are kept out.

Recommendations

- → install a fully automated air conditioning system with filters
- → ensure good circulation of air to avoid mould infestation
- → set temperatures to 13 – 15°C (max 17°C) for most types of collections
- → if funds are limited, keep temperatures below 20°C to keep pests at low levels
- → 45 – 55% relative humidity is ideal for most natural history collections
- → keep fluctuations in relative humidity to an extreme minimum and avoid long periods above 60% relative humidity

Product	Recommended relative humidity	Recommended temperature range	Temperature with respect to pests	Reasons for temperature recommendation
leather	40% RH		13 –15 °C	
keratin	58% RH	13 –15 °C	13 –15 °C	pests
mix of leather/keratin	55% RH	13 –15 °C	13 –15 °C	pests
bones	55% RH		13 –15 °C	
archaeological bones	50% RH	13 –15 °C		reduce ageing
dentin / teeth / mammoth tusks	58% RH			
calcite shells (eggs, muscles, snails)	40% RH			
chitin (beetles, butterflies)	40% RH	13 –15 °C	13 –15 °C	pests
plants, bird nests	45% RH	13 –15 ° C	13 –15 °C	pests
wet collections	55% RH	15 –17 ° C		reduce flash point

Figure 3.2.3.c: Temperature and relative humidity (RH) conditions recommended by taxidermist Martin Troxler from the NMBE in Bern

Examples

- skins, mounts and furs are kept at 12 – 14°C and at 45 – 55% (< 60%) relative humidity to avoid pest infestations at the NMB in Basel
- mineralogical, anthropological, invertebrate, palaeontological, fossil, subfossil, osteological and wet collections are stored at 16 – 20°C in the NMB in Basel to avoid corrosion, evaporation and moulds (depending on the relative humidity). A relative humidity of 30 – 40% is provided for invertebrates and palaeontological collections, 45 – 55% relative humidity for mineralogical, anthropological, fossil, subfossil and osteological collections and 50 – 60% relative humidity for wet collections
- the zoological and botanical collections deposited in the NAAG in Aarau are kept at 17°C (22°C during summer). Given that collections are kept in a space under the roof, the optimal temperature of 13°C cannot be reached in the collection, despite the presence of air conditioning
- cooling and dehumidification systems Kelvion, type KDC-352-6AN-Hx and a VA 150 ventilation system are in use at the BNM in Chur. Their fully automated air circulation system is programmed, monitored and supervised (including an alarm if the defined range is not met) by Siemens. The climatic conditions in the collections are thus kept as stable as possible
- to adjust and stabilise the relative humidity of display cases and of whole rooms, the BNM in Chur uses PRO SORB. The silica gel or silicon dioxide can absorb and release moisture thanks to its large surface area. PRO SORB is particularly effective at values of 30 – 60% relative humidity
- a seasonal fluctuation in temperature between 13°C and 15°C is permitted at the BNM in Chur
- the vertebrate collections are kept at 16°C (+/–1°C), and the insects at 18°C (+/– 2°C) at the MZL in Lausanne. The relatively high temperature for the dry insect collection is partly due to technical constraints and is not considered 'best practice'

Suppliers

- for the planning of cooling systems such as those found in the BNM in Chur, see FE-Partner AG (Vaduz FL, www.fe-partner.com)
- for humidity absorbers (silicone dioxide, i.e. silica gel) in cabinets, see PRO SORB by the Dry and Safe GmbH (Oensingen CH, www.trockenmittel.ch/klimatisierung-von-vitrinen.html)
- for planning the air conditioning system of a collection facility, contact PrevArt GmbH (Winterthur CH, www.prevart.ch)

Further reading

- for the effects of temperature and relative humidity on collection objects, as well as recommendations concerning optimal ranges, see Michalski (2017a, b)
- for a discussion on manual aeration and its consequences on climate, see Kotterer (2004)

3.2.4 Specific conditions in wet collections

Climate is very important for the storage of wet collections. The collection room should be dark and all lights UV filtered.

Temperature and relative humidity

Temperature has a strong influence on the evaporation rate of preservation liquids and on the deterioration of certain storage materials. Ethanol evaporates quickly at temperatures above 21°C, and formaldehyde can polymerise if stored below 10°C. Temperatures in wet collections should remain constant, ideally between 15 – 17°C. Temperatures above 20°C are unfavourable for long-term storage in wet collections. Large fluctuations can lead to cracking or opening of seals due to pressure changes in jars. Please note that ethanol expands or contracts about eight times more than water. Therefore it is important to cover the objects with enough liquid, otherwise there is a risk that the objects are not covered with liquid when they are transported into a cool room.

Moisture can promote mould growth on the labels of jars. Corrosion of metal lids and clip-top jar holders is accelerated by high relative humidity levels. It is therefore important to maintain a relative humidity between 50 – 55%.

Ventilation

The storage area should be well-ventilated. According to the Federal Coordination Commission for Occupational Safety (FCOS 2005), the ventilation system in storage spaces housing highly flammable liquids should provide complete air renewal 3 to 5 times an hour and have an air vent located near the ground.

The forced ventilation with additional extraction near the floor must be designed independently of the other rooms and must necessarily work with outside air. Air conditioning is expensive but effective.

Security measures

The working area must be constructed according to the applicable explosion protection regulations to protect the staff, objects and the facilities. It is legally required for institutions with more than 50 employees to consult a specialised company for the planning of such security measures, such as anti-EX (i.e. explosion-protected) installations. It is recommended that institutions with smaller staff numbers also seek specialised advice. This is due to the high risks of explosion associated with the preserving fluids due to the fumes that are given off when jars are opened, either for examination of specimens or when more fluids are added to the storage containers.

The room must also have an emergency station equipped with absorbent material to deal with accidental spills of alcohol, formaldehyde and other preservation liquids. The floors should be made of a material that does not absorb liquids and the area below the liquid samples should be outfitted with an adequate drainage system in case of accidents (Carter and Walker 1999).

An alcohol vapour detection system in the room is useful for alerting staff when vapor levels go above a certain threshold, thus allowing measures to be taken to reduce the risk of fire and explosions.

Figure 3.2.4.a: Different generations of glass container types in the wet collection of the NAAG in Aarau (photo Holger Frick)

Recommendations

- → set temperatures between 15 – 17°C as below 10°C, formaldehyde polymerises and above 21°C ethanol evaporates more rapidly
- → set the relative humidity between 50% and 55%
- → keep wet collections in the dark and include UV filters on lights
- → install forced ventilation, independent of the other rooms, with additional floor-level extraction
- → use smooth, easy to clean surfaces that do not absorb liquids
- → install EX-protected (explosion protected) electrical systems
- → install an emergency station to absorb liquids like alcohol, formaldehyde etc. in case of accidents

Example

- the new storage building for wet and entomological collections of the MHNG in Geneva will be set at 14°C (+/– 1°C) temperature and 55% (+/– 5%) relative humidity

Supplier

- for consultation and installation of air conditioning and control, contact PrevArt GmbH (Winterthur CH, www.prevart.ch)

Further reading

- for a summary on safety regulations, see FCOS (2005)
- for a summary on storage of fluid preservatives, see Simmons (2019)

3.3 Object treatment before integration

Before integration or reintegration into an existing collection, objects should be placed in quarantine and checked for mould or pest insect infestation (Petrak 2020). Mould-infested objects and objects with a suspected insect infestation should not be isolated in the same quarantine room as other matierial. If there are signs of pest infestation the object should be treated accordingly. This section deals with the treatment of single to large numbers of objects to be integrated into an existing (pest-free) collection facility.

Pests can enter the collection in various ways. They may be accidentally introduced into collection spaces due to a failure to properly disinfest specimens that enter into the collection. Such introductions may happen in many ways and include the integration of new collections gathered by the scientific staff, new acquisitions associated with exchanges, purchases and donations, packaging material not subjected to the disinfestation process, third-party use of collection facilities, transit of non-scientific, non-disinfested material (e.g. for mounting, conditioning, restoration activities) and the return of loan material into the general collection prior to proper disinfestation, among others.

It is also important to understand that a collection that is air-conditioned and cooled to low temperatures to protect against pests is not necessarily pest-free. Pest insects may be present in a dormant phase and eggs or pupa are often small and can be quickly overlooked. When stored under cool conditions, the insects are incapable of completing their life cycle. If an infested object is warmed, however, development can resume and populations can develop rapidly. For this reason, objects from collections should be quarantined before they are placed in exhibitions or loaned out. If either feeding damage or larval or adult pests are detected during quarantine, it is advisable to call in a specialist to disinfest the objects or to train staff to handle such problems and deal with them in-house.

Figure 3.3.a: Herbarium of the NMWIN in Winterthur (photo Sabrina Schnurrenberger)

Recommendations

- → an inert method, like treatment by oxygen deprivation, is best
- → quarantine specimens before integration into a collection
- → clean and check specimens for harmful insects and mould before integration
- → create a policy, such as 'any object removed from the collection for more than 24 hours must be disinfested before reintegration'

Example

- the CJBG in Geneva tested how long material could remain in staff offices without having to disinfest them before reintegration. For herbarium sheets, it is less than one day between April and October and a maximum of 5 days between November and March. Following these guidelines, all material that has been out of the collections for longer than the specified limits is disinfested before returning to the collection

Supplier

- for further training and training courses run at its annual conferences, consult the Swiss Taxidermy Association (VNPS/FSPSN, www.vnps.ch)

Further reading

- for pest insect monitoring and measures, see Troxler (2014)

3.3.1 Disinfestation by flash-freezing

Flash freezing is a rapid, inexpensive procedure that can be performed using equipment that is readily available on the market. It works by reducing the metabolism of the pest insects until they are killed (Petrak 2020). Treating the specimen at an appropriate relative humidity and properly packaging the specimen prior to treatment are both essential for avoiding damage to the specimen caused either by the formation of water crystals during

treatment or the condensation of moisture on the specimen after treatment (Petrak 2020). This is particularly relevant in specimens that are highly sensitive to moisture like dried insects and specimens on herbarium sheets or in herbarium packets (bryophytes and fungi).

Flash-freezing and its function

The flash-freezing process can kill the adults, larvae and eggs of pest insects. For the flash-freezing treatment, proper packaging of infested specimens is essential to avoid damage caused by the condensation of water on the specimen. Pack the specimens in an airtight container, such as a Polyethylene bag, and close the opening with adhesive tape. The bag should not touch the specimen to avoid displacement of parts of the object, for example, feathers and hairs etc.

For the treatment, the relative humidity should be around 50–55%. Otherwise, water could freeze inside the object and harm it. Do not use additional materials for packaging, like acid-free paper or silica gels (Petrak 2020).

For a proper flash-freezing process, the specimens should be placed directly on or very close to a frozen surface. This can be done by placing the specimens in an appropriate freezer or by putting them on the floor of a freezing room in contact with frozen surfaces. Do not flash-freeze the specimens on the shelves, since air is a slow temperature transporter; the coldest place in a freezing room is the floor. Pallets should not be used due to the insulation effect created by the air below them.

The low temperatures should get to the specimen and its core as quickly as possible, since pest insects can partially avoid contact with cold by moving to a more insulated place on or in the specimen. Although adult insects and larvae are killed by flash-freezing, both eggs and pupae are sometimes able to survive this process. A period where the specimen is removed from the freezer and allowed to come back to room temperature gives the eggs and pupae that may have survived the freezing cycle a chance to hatch or eclose. A second treatment in the freezer kills any newly hatched larvae or newly emerged adults. Therefore, specimens should be flash-frozen in two rounds instead of one extended period.

Freezing can be problematic with composite or glue-based materials. The temperature and length of the freezing sequence varies from institution to institution. See examples.

Figure 3.3.1.a: Freezer with an herbarium trolley in the herbarium of the CJBG in Geneva (photo CJBG)

Recommendations

- → seal non-delicate objects as tightly as possible in polyethylene bags before freezing to avoid condensation, like books or herbarium sheets
- → use light, thin plastic for packaging. Stiffer PE-foils can damage sensitive collection material, like full mounts of birds and mammals
- → packaging plastic should not be in contact with the object
- → flash-freeze to at least –22°C for 10 days (better –24°C for 14 days) to freeze the object to the core
- → induce a rapid temperature drop in the critical phase from 5°C to 0°C to prevent the insect from launching a physiological protective response against the cold
- → bring the object slowly back to room temperature after freezing
- → repeat procedure at least once
- → before the object is unpacked, it has to reach room temperature

Examples

- the zoological collections of the NAAG are frozen at –24°C for 14 days, then kept at 5°C for 2 days and then at room temperature for 14 days. The cycle is repeated at least once
- in the CJBG in Geneva, for disinfestation by freezing, herbarium sheets in piles of 15–20 cm hight are wrapped in polyethylene bags and tightly sealed with adhesive tape. They are placed in a freezer at –30°C for at least 8 days, then left at room temperature for 1–2 days until any condensation disappears before they are filed in the general collection. Previous studies stated that temperatures between –20°C to –25°C were adequate for treatment but nowadays most herbaria treat specimens at –25°C to –30°C, with some using temperatures as low as –40°C (Pacaud 1996)
- for most materials, the 'Sammlungszentrum' of the Swiss National Museum (SNM) freezes wrapped objects at –30°C for 7 days, then keeps them at room temperature for 7 days. They are then frozen again at –30°C for 7 days, in order to ensure that any newly hatched larvae are killed. A potential alternative to kill all developmental stages is freezing for 21 days at min. –20°C
- to move the specimens, the BNM in Chur uses a baking tray trolley with height-adjustable shelves

Suppliers

- get baking tray trolleys from Hupfer Schweiz AG (Sempach CH, www.hupfer.com/en)
- get polyethylene bags from Plastic Haus AG (Arlesheim CH, www.plastic-haus.ch)

Further reading

- for an analysis on the advantages flash-freezing in herbaria see Pacaud (1996)

Figure 3.3.2.a: Wood cut collection at BOGA in Bern (photo Katja Rembold)

3.3.2 Hot-air treatment

This treatment can be used for wood samples (see figure 3.3.2.a), as well as for bird nests. However, it is not suitable for all types of objects, as the temperature causes lasting damage to collagen proteins. Basically, it kills insect pests by denaturing their proteins when exposed to temperatures above 50°C. The core of the aggregate sample should reach 58 – 60°C for at least 24 hours (Petrak 2020). It is important to keep the relative humidity stable, i.e. the absolute humidity must be adjusted during heating and cooling, to prevent samples from cracking.

Heat treatment is prohibited for all mixed materials, especially for animal preparations where natural fats and incompletely tanned protein fibres are still present in the skin or bones themselves, or where waxes and/or paints have been used during processing. Special equipment is required for this method.

Suppliers

- Thermo Lignum GmbH (Salzburg AT, www.thermolignum.at)
- Desinfecta AG (Deisswil bei Stettlen CH, www.desinfecta.ch)
- Haböck and Weinzierl Holz- und Bautenschutz KG (Salzburg AT, www.feuchtemauern.at)
- Bernisches Historisches Museum (Bern CH, www.bhm.ch)

3.3.3 Treatment by oxygen deprivation

Treatment by oxygen deprivation is currently the most efficient method of disinfestation and for the objects themselves represents the least harmful way of killing pest insects. In a chamber, oxygen is extracted by means of a compressor to generate nitrogen. It kills pests by exposing them to an oxygen-free environment, i.e. the insects suffocate (Petrak 2020). To be effective, the oxygen level must be below 1%. In the 'Sammlungszentrum' of the Swiss National Museum (SNM), the treatment lasts for 8 weeks. However, the duration depends on residual oxygen content and temperature: the higher the temperature and the lower the residual oxygen content, the shorter the treatment time. The temperature regime is important and should not be below 20°C.

All organic specimens can be treated with this method. Advantages are that the method is not hazardous to the environment and no damage is caused to the specimens themselves (Petrak 2020). However, the long treatment time has to be taken into consideration.

Recommendations

- → use treatment by oxygen deprivation to control pests. It is the best option, especially if large specimens or a significant volume of specimens have to be treated at the same time
- → treat specimens at <1% residual oxygen for 8 weeks at room temperature (at or more than 20°C) and adapt the relative humidity of the chamber to the specific needs of the material to be treated
- → do not pack objects in sealed plastic-bags as this retards the quick extraction of oxygen to achieve < 1% levels

Example

- at the 'Sammlungszentrum' of the Swiss National Museum (SNM), specimens are treated as follows: the period of treatment is 8 weeks. In addition, there is a start-up phase of 5–7 days until the desired nitrogen content is reached. The chamber is climate-controlled. During the treatment process, the climate is kept stable at a temperature of 20°C (+/– 2 °C) and a relative humidity of 50 % (+/– 2 %)

Suppliers

- private companies like Desinfecta AG (Deisswil bei Stettlen CH, www.desinfecta.ch) and Welti-Furrer (Dielsdorf CH, www.welti-furrer.ch) offer treatments by oxygen deprivation
- mobile devices like tents are offered by Rentokil Schweiz AG (Oberbuchsiten CH, www.rentokil.ch) and Welti-Furrer
- local facilities for treatment by oxygen deprivation are available at the following collection institutions: e.g. NMBE (Bern CH, www.nmbe.ch), LLM (Vaduz FL, www.llm.li) and the SNM (Affoltern am Albis CH, www.sammlungszentrum.ch/en/services/nitrogen-treatment)

Further reading

- for a description of treatment by oxygen deprivation, see Petrak (2020)

3.3.4 Poisons

The use of poison to kill insects in natural history collections has a long tradition. The objects in various collections and cultural institutions are already heavily contaminated. Most of the poisons in use can be extremely effective against pest insects (and for controlling problems they cause) but are often also harmful for humans. Therefore, most substances are no longer recommended nor allowed for use. As long as remains are in a collection it is considered as contaminated. However, in the case that contaminated objects are de-accessed from a collection, they must be treated as hazardous waste.

Since 2013, it has been forbidden to treat stored objects with biocides and the transition period ended 2017. It is strongly advised to follow the so-called Biocidal Product Regulation, i.e. the Regulation (EU) No 528/2012 of the European Parliament concerning the commercial availability and use of biocidal products (EU 2012).

Poisons used in collections

For centuries, natural history objects, including herbarium sheets, were protected from pests by the use of different poisons. All these poisons formed insoluble compounds upon contact with the objects and are still present in historical collections today. In addition to being present on the objects themselves, these products are also often found in the underlying dust in collections.

During preparation, specimens were treated with arsenic in different forms, including arsenic soap and arsenic trioxide, as well as with mercury (II) chloride and Eulan (prohibited to use for preparation since September 01, 2013, like other substances). DDT, Lindane, paradichlorobenzene, methyl bromide and naphthalene and more modern but no less hazardous wool preservatives derived from Eulan and Mitin are also present in collections.

For herbarium sheets, mercury, DDT and methyl bromide were commonly in use. Until recently, the highly toxic and environmentally harmful gases sulfuryl fluoride (SO2F2) and phosphine (PH3) were also used to disinfest botanical collections. Altogether, about 20 different poisonous substances are known from historical herbarium sheets alone.

Meanwhile, the use of all these products is prohibited by the EU Biocide Regulation, especially in the field of natural history. It is now considered best to protect objects from pest infestations by means of physical measures (see section 3.2.3) and a consequent integrated pest management (IPM).

Figure 3.3.4.a: The herbarium of the Z+ZT in Zürich (photo Reto Nyffeler)

Recommendations

- → the treatment of cultural objects with poisonous substances is prohibited
- → follow the EU Regulation No 528/2012 on biocidal products (EU 2012)
- → despite the advantages of different poisons, treatment by oxygen deprivation to generate nitrogen is the preferred preventive method before integration in collections (see section 3.3.3)
- → follow integrated pest management measures like prevention, treatment by oxygen deprivation and monitoring (see sections 3.3 and 3.4)

Further reading

- for an overview on harmful substances in natural history collections and protection measures, see Spiegel et al. (2019)
- for an overview on biocides in collections, see Troxler (2017) and Probst et al. (2019)

3.4 Detection and monitoring

Monitoring collections is an important part of the daily work of collection managers. Fortunately, many methods are available to facilitate this undertaking, especially for monitoring the physical conditions in the collection.

Pest insects and mould are the most common biological threats in zoological and botanical collections. The degree of infestation can vary from light levels that are relatively easy to control, to a critical level that can destroy whole collections. The detection of such infestations at an early stage is therefore essential. Traps should be regularly checked and collection facilities inspected to assess the presence and development of biological infestations.

Collections monitoring is thus a prerequisite for the early detection and prevention of pest infestations. This is only possible if storage surfaces (and rooms) are clean. Monitoring means the targeted examination of objects and their surroundings at fixed intervals. Data must be recorded in order to compare the development of infestations over time. The data can also be used to draw up a map of the area and locate particularly susceptible objects. This is especially important in warm rooms, including exhibitions.

This section deals with the different approaches that are either in use or could potentially be used in Swiss natural history collections for monitoring. If threats are detected, possible interventions can be found in section 3.5.

Recommendations

- → check collection regularly for signs of pest insects and mould
- → keep the collection clean

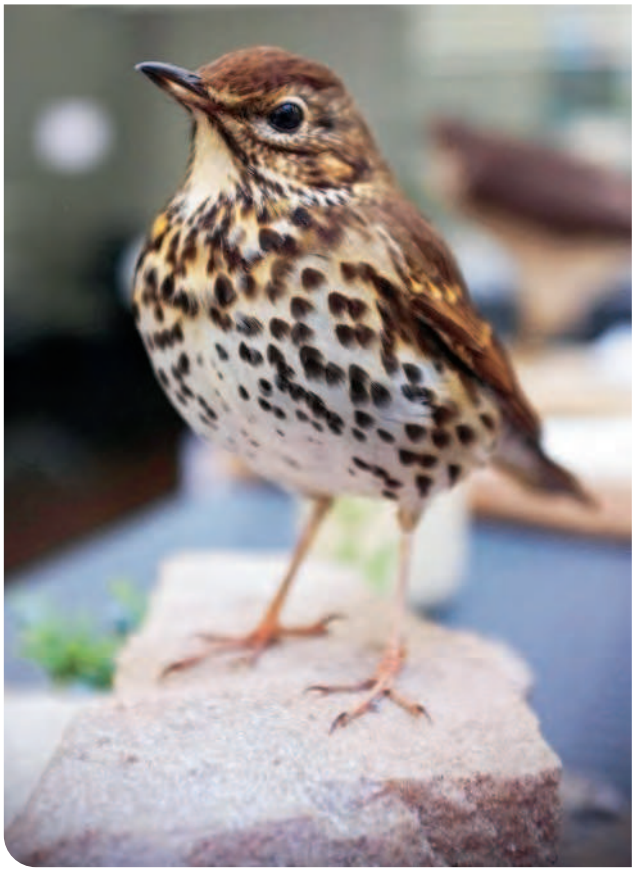

Figure 3.4.a: Bird full mount in perfect condition, showing no signs of pest insects on the plumage or the bright storage surface of the NMB in Basel (photo Basil Thüring)

3.4.1 Temperature and relative humidity

Monitoring temperature and relative humidity is essential in storage rooms and responsible personnel should be familiar with the relevant procedures.

Detection

Temperature and relative humidity should be monitored automatically and connected to an alarm system. This is especially important if collection facilities and working rooms are separated. Ideally, climate data are sent to the curators or in-house technicians in real time and not just recorded locally. In this way changes can be detected quickly and measures can be taken immediately. If the data-loggers are not connected to an alarm system, they should be checked regularly, since mould outbreaks can develop quickly if climatic conditions change and become suboptimal for conservation (see section 3.5.2).

Data loggers can be used not only to detect changes in climatic conditions but also to assess if climatic conditions are homogeneous within a storage room. This is particularly important in facilities with closed cabinets and limited air circulation. Data loggers can also be used to double check if the parameters set for the air conditioning are met. If outbreaks of mould are detected late, the data loggers can be consulted to see if there were past climatic changes that can be linked to the outbreak. There are several commercial suppliers of good-quality electronic data loggers that measure temperature and relative humidity

Figure 3.4.1.a: Insect drawer with Carabid beetles from the Reinacher Heide around 1990 in the AMBL in Liestal (photo Andreas Zimmermann)

every few minutes (von Lerber 2016). They should also be installed in fully automated air-conditioned rooms as a means of verifying conditions.

Short term emergency measures

If temperature or relative humidity exceed the desired range, simple measures can be taken for short periods of time. For example, if an air conditioning unit requires repairs, needs to be changed or simply cannot cope with a heat wave during summer, immediate solutions must be found. It is important to be prepared for such events at any time, for example, by maintaining service contracts with the air conditioning system supplier that include provisions for emergency services. In smaller facilities, however, commercial mobile dehumidifiers and air conditioners may be an interim solution for keeping temperatures and relative humidity at a reasonable level for a short time. Such solutions, however, are suboptimal emergency measures and the proper positioning of such temporary devices within a collection space is important to maximise their potential for climate control.

Recommendations

- → track temperature and relative humidity with a data logger with user-friendly data analysis options
- → if possible, connect the temperature and relative humidity detectors to an alarm system or at least check data regularly
- → be prepared for emergency situations, for example, by having a mobile dehumidifier and air conditioner units ready for use

Examples

- mobile data loggers are used in storage rooms without air conditioning at the NAAG in Aarau. They use two systems. The first are the precise and highly reliable USB-loggers by LASCAR that measure conditions in the collection and whose data can later be read on a computer. The second are KlimaLogg Pro devices that measure conditions in the collection and send the data in real-time to a second device up to 100 m away. However, the logging of data is not always reliable. Temperature and relative humidity are also monitored automatically by the air conditioning system (Marlabur)

- relative humidity and temperature are monitored using ESCORT iLog humidity loggers in the collections and in the exhibition rooms of the BNM in Chur

Suppliers

- get KlimaLogg Pro (Kat.Nr. 30.3039.IT) from TFA Dostmann GmbH and Co. KG (Wertheim-Reicholzheim DE, www.tfa-dostmann.de)
- get EasyLog, EL-USB-2-LCD+ from Lascar Electronics Ltd (Whiteparish UK, www.lascarelectronics.com)
- get humidity loggers like Escort iLog from Escort Messtechnik AG (Aesch bei Birmensdorf CH, www.escort-instruments.ch)
- get dehumidifiers like a Krüger KRG 80 HE from Luftentfeuchter-shop (Nidau CH, www.luftentfeuchter-shop.ch/261-bautrocknung)

3.4.2 Pest insect detection

Detecting pests is not an easy task. Traps are a good start but alone they are insufficient for monitoring. Storage facilities, such as shelving, should also be checked regularly for signs of pest insect attacks. Such signs include the presence of insect debris, dust deposits (see figure 3.4.2.a) and fallen hair and feathers. The individual objects should also be checked regularly by an expert on pest infestation. Both measures should be carried out at least once a year.

Suggested detection and monitoring methods for the detection of pest insects include sticky traps, pheromone traps, UV- and other light traps and baited traps (Petrak 2020). Traps can highlight the presence of an infestation, its location, its local growth, its spread as well as serving as an indicator of the efficiency of other pest control measures (Petrak 2020). Traps can thus be considered as an aid in the battle against pests but not as the only solution.

If pest insects are detected, they should be identified to determine appropriate pest control measures (see section 3.5).

Diversity of pest insects in collections

Different species of pest insects are associated with different types of collections. Zoological collections are most often infested by larvae of dermestid beetles belonging to the genera *Anthrenus (A. verbasci, A. scrophulariae, A. museorum)* and *Attagenus (A. pellio, A. smirnovi)*, commonly referred to as museum and carpet beetles (see figure 3.4.2.a), as well as the common clothes moth *Tineola bisselliella*.

In botanical collections, such as herbaria, most publications dealing with the subject (i.e. Stein 1986, Hall 1988, Valentin 1993, Bačič 2010) have identified the following insects as the most important pests in herbaria: the tobacco beetle *(Lasioderma serricorne)*, the varied carpet beetle *(Anthrenus verbasci)* and the dermestid *Trogoderma angustum*, the silverfish *(Lepisma saccharina),* the German cockroach *(Blatella germanica)* and booklice of the genera *Liposcelis* and *Trogium*. The tobacco and the carpet beetles are the most harmful pests. They have a generation time of around 2–3 months, depending on the temperature, and their numbers can be stabilised using UV light lamps and pheromone traps.

Certain plant families like the Asteraceae s.l., Brassicaceae, Capparaceae and petaloid Monocotyledons (i.e. Liliaceae s.l.) are particularly susceptible to attack by herbarium pests and should thus be monitored frequently (for details see Bridson and Foreman 2000, Bačič 2010). Interestingly, the biscuit beetle *(Stegobium paniceum)* mostly attacks latex-containing families such as Apocynaceae (s.l.).

Figure 3.4.2.a: Beetle after infestation with *Anthrenus* larvae. The internal parts of the insects are reduced to dust while the exoskeleton stayed almost intact (MZL, photo Michel Krafft)

Pests in exhibitions

In exhibition spaces, food and drinks are the main attractors of pest insects. Monitoring efforts in exhibitions should thus be increased in zones where these are allowed. The presence of any food remains makes efforts to keep pests under control difficult to impossible. If culinary events take place in exhibition rooms, the affected part of the building must be cleaned immediately after the event and the rubbish disposed of outside. Cooking in exhibitions or adjacent facilities should not be permitted. Greasy or strong-smelling substances may form deposits on exhibited objects and attract pests.

Figure 3.4.2.b: Regular monitoring insect pest infestations is especially important in exhibitions including mammals and birds as in the MHNF in Fribourg (photo Michael Maillard)

Placement and monitoring of traps

Independent of the type of methods used, all traps should be labelled with a date and an object number. Given that pest insects will most likely move through a collection space by remaining close to walls and in dark corners, traps should be placed on the floor, close to windows and doors, in corners and along walls, rather than in open spaces. Traps should be monitored regularly (min 3, ideally 6 times a year) and their positions should be marked on a ground plan. Traps should be replaced regularly, since they lose their attractiveness or effectiveness with time (see recommendation of the producers). Specialised companies can help institutions to set up monitoring regimes and they should be consulted in case of need.

UV light traps

These traps are mainly used to catch flying insects (see 3.4.2.c). UV light traps principally attract adult insects and catch them before they can deposit eggs on the objects. However, UV light has the potential to cause great damage to collection objects and also has a strongly negative effect on human health. Therefore, such traps must be oriented in such a way that objects are never directly exposed to UV rays and so that collections personnel are not exposed to direct UV light when checking the traps. An alternative to UV light traps are green light traps, such as those provided by Abiotec. Green light is also attractive to insects but is less harmful to collection objects and to human health.

Proper maintenance of traps is important. The surfaces of the traps must be systematically examined and replaced regularly. The frequency with which they are replaced should be appropriate.

If the purpose of the traps goes beyond detection, specialised companies should be called upon for the implementation of control measures. As a rule of thumb, some sources suggest replacing the sticky surfaces every month between March and September, i.e. during the period in which most insect infestations develop, and every three months between October and February. Also, the fluorescent tubes of the UV lamps and the starters should be replaced at least once per year. Although UV light traps alone are not sufficient for monitoring, they can be effective for monitoring certain insect populations, such as *Anthrenus verbasci* and *Trogoderma angustum*. The sticky surfaces of UV light traps with the trapped insects are also ideal for educational purposes, such as explaining the importance of integrated pest management.

Sticky pheromone traps

There are different types of pheromone and sticky traps that are effective at trapping and monitoring both flying and crawling insects. One type of sticky trap has an adhesive surface which is impregnated with pheromones, i.e. artificial female scents, that attract males. In another type, the pheromone is positioned in the centre of the sticky trap in the form of a capsule. Such traps can be affixed to the floor with an additional double-sided adhesive tape, ensuring that any insects trying to crawl under the trap will be trapped, as well. This method has worked well

Figure 3.4.2.c: UV trap to attract flying insects at the NMBE in Bern (photo Constatin Latt)

at the NMBE in Bern. Larvae seek protection, crawl under the trap and stick to it. Pheromone traps should only be set up by qualified personnel and should be checked/replaced every 1–2 months, depending on the degree of infestation. Inappropriate placement can be unattractive to pest insects or can even attract insects from the outside. Too many or poorly placed pheromone traps may thus give insufficient indications of possible infestation.

Tracks of pest insects

Tracks of pest insects can only be detected if storage surfaces and objects are clean. Specimens should therefore always be cleaned before integration in an existing collection. Keeping the storage surfaces clean can facilitate detection of fresh tracks as well as helping to differentiate between old and new tracks.

Live pest insects can sometimes be seen on the surfaces of collection objects (Petrak 2020). Pests may include crawling adult beetles and flying moths but also crawling larvae. Fresh tracks or holes in fur, feathers or skins are sometimes found either on the specimen or below it. In herbarium specimens debris can be present on or below the specimen, or obvious signs of damage may be visible (consumption of plant material, labels etc). Depending on the pest species, powdery debris, eggs, faeces, body parts and dead pest specimens can also be found below the stored objects (Petrak 2020). These are best detected if the storage surface is very light or dark, which is rarely the case with wooden racks. Alternatively, light or dark coloured acid-free paper can be placed under objects where there is suspicion of an infestation (Petrak 2020).

Recommendations

- → use traps to detect pest infestations. They are not sufficient alone but are a good support for other pest insect control measures
- → ensure that traps are appropriate for the target insect(s)
- → check traps based on a fixed schedule 3–6 times a year
- → keep collection facilities clean to allow for the immediate detection of signs of infestation
- → forbid food and drinks in collection facilities and exhibitions
- → use only indirect UV light in collections. Objects must not receive direct UV rays
- → change UV light tubes at least every 12 months
- → use sticky pheromone traps for flying or crawling pest insects
- → sticky pheromone traps should be positioned and monitored by a specialist company
- → keep specimens clean with special hazardous material vacuum cleaners with a U16 ULPA filter and dust-collecting dry cloth.
- → place objects that are suspected of being infested on white paper to detect fresh excrement or other debris

Examples

- for an established monitoring system in a zoological collection, see the NMBE in Bern. Trap monitoring is carried out externally by the company Desinfecta, while the objects and their surroundings are monitored by the taxidermists
- to keep the collection clean, the BNM in Chur worked out a detailed cleaning plan with the caretakers. It specifies which areas should be cleaned and how often per year. The aim is to clean the entire facility at least once a year
- for the monitoring of cryptogamic and phanerogamic herbaria, see CJBG in Geneva. The monitoring programme focuses on the detection of insects by means of pheromone traps for crawling insects (checked 4 times per year) and UV lamps for flying insects (checked 6 times per year)
- UV light traps with fluorescent tubes emitting light at a wavelength of 365 nm (optimal according to Fohrer 2020) are used in the Cryptogamic and Phanerogamic herbaria of the CJBG in Geneva
- UV light traps are used to monitor *Anthrenus verbasci* (Linnaeus, 1767) and *Trogoderma angustum* (Solier, 1849) in the

BNM in Chur with great success. Two UV light traps are positioned in the scientific collection, one in the museum's educational collection and one on each floor of the permanent exhibitions. In addition, a mobile UV lamp was designed for the course rooms with temporarily exhibited displays
- to detect the entry of pest insects into the collection facility via cracks or the door, and to find potential infestation patterns or infestation hotspots, the Naturama Aargau uses commercial sticky traps by Optimum
- bait traps for dermestid beetles (Blp storage monitors) are used in the scientific collection of the BNM in Chur

Suppliers
- for detection and monitoring pest control measures contact Desinfecta AG (Deisswil bei Stettlen CH, www.desinfecta.ch)
- get UV light traps like Chameleon 1x2 and Chameleon Uplight from e.g. Desinfecta AG
- get green light traps with no UV emissions from Abiotec (Le Plessis-Robinson FR, www.abiotec.com)
- get sticky traps, like Biolock®, from Agrinova GmbH (Quirnheim DE, https://agrinova.de)
- get different types of traps from Futura GmbH (Borchen DE, www.futura-shop.de) or PPS GmbH (Schlierbach DE, www.pps-vertrieb.de)
- get moth traps from e.g. Andermatt Biogarten AG (Grossdietwil CH, www.biogarten.ch)
- get bait traps for Dermestidae like Blp-Lagermonitors from Biologische Beratung (Berlin DE, www.biologische-beratung.de)
- for training courses on request about detection of traces, contact the Verband naturwissenschaftliche Präparation Schweiz VNPS/FSPSN (www.vnps.ch)

Further reading
- for the identification of pest insects, see Notton (2018)
- for pest insect monitoring and management, see Troxler (2014)
- for a comprehensive guide to the identification of pest insects and integrated pest management in museums, see Story (1985)
- for information specific to herbaria, see Hall (1988)

3.4.3 Mould infestation detection

Mould on collection specimens is similar in appearance to mould on food. It should be carefully brushed off tainted specimens before their integration into the collection (see section 3.5.2 for methods). Spores are usually present on specimens and in collection facilities although they are almost impossible to see with the naked eye. However, mould that is growing or traces of developed mould can be detected (Petrak 2020).

Detecting an outbreak

If outbreaks of mould have occurred, the tainted objects and their respective storage spaces should be labelled so that they may be monitored on a more regular basis. If the relative humidity rises above approximately 60–65% relative humidity, these same specimens are more likely to develop mould growth. In other words, objects that have suffered problems with mould growth in the past are more likely to develop an active mould infestation than objects that have never exhibited mould growth, even at low relative humidity (von Lerber 2016).

Storage rooms should also be checked for mould infestations. This is especially important in storage facilities with previous water damage issues. Indications are a musty damp smell, a visual search of the damp area indicating new growth or traces of mould in the filters of the air conditioning system. The activity and type of mould can be

Figure 3.4.3.a: Herbarium sheet in perfect condition, showing no signs of mould infestations in the NSFL in Triesen (photo Sven Beham)

determined by taking a mould sample from the object and then cultivating the fungus on culture media.

Moulds often exhibit UV fluorescence that can be detected with a commercial UV lamp for conservation and restoration (366 nm). Bleached discolourations caused by moulds can be visible under UV light. The absence of fluorescence, however, is not sufficient to conclude that moulds are also absent, because not all moulds fluoresce in UV light (Kaese et al. 2008). The most important and common mould species are listed in Hilbert (2002).

Moulds on herbarium sheets

On both paper and herbarium sheets, it is possible to detect moulds visually by eye or with a magnifying glass. Depending on the type and extent of the infestation, the appearance can vary from small spots with fungal-like growths to large blurry areas. Stain-like discolourations in various colours and water damage should always be carefully examined for mould. Appelbaum (2018) writes: 'There are […] many things that are mistaken for mould because, like mould, they leave dots on surfaces. An examination under low magnification should reveal the facts. Mould has a fungal-like structure, with thread-like filaments (hyphae) and spherical attachments (fruiting bodies). By contrast, soluble salts, some corrosion products, dried wax or oil, and mothball residues have crystalline structures. Dots from paint splatter have no structure at all'. Meier and Petersen (2006) point out that due to the degradation processes of mould, the absorbency of paper may be altered. These changes only become apparent when the object is moistened. The damaged areas absorb water more quickly and discolouration can occur.

Recommendation

→ check collection regularly for fresh traces of mould, like changes in surface colour of specimens, growing mould, fruit bodies and deteriorated organic matter

3.5 Intervention and control

Once an infestation is detected (see section 3.4), appropriate measures should be taken according to its severity. With proper monitoring, some infestations can be kept on a low level (see section 3.4). But in other cases, certain insects and especially mould can develop into a major problem. In the case of serious infestations, careful planning and the avoidance of hasty decisions are essential for adopting a suitable course of action. Some of these measures are described and referred to in this section.

Evaluate the degree of infestation

Before taking any measures, the following questions should be answered to evaluate the infestation (Petrak 2020): Is there any damage? If so, what kind of damage is it? Are there insects, either dead or alive? Are there traces of pest insects? Is there an active or inactive fungal infestation? How extensive is the infestation? How many and what kind of objects are infested? What species of pest insects or moulds were detected? At what life stage are the insects or mould? In what facilities were the infestations detected?

Recommendations

- → isolate the infested objects from the uninfested ones by transferring them into a quarantine room, if possible. Packing infested objects in polyethylene film also works in the short-term
- → proceed carefully and avoid hasty decisions that may cause more harm than good, especially in the case of mould infestations

Further reading

- for an overview on integrated pest management (IPM), see Strang et al. (2019)
- as a quick guideline to detect and cope with pest infestations, see Petrak (2020)

3.5.1 Pest insects

A pest insect problem usually does not happen randomly. If there is an outbreak, there are usually reasons for it, for example, its development went unnoticed. If an outbreak happens, it is wise to re-examine and possibly adapt the monitoring procedures. It is essential to have an action plan for tackling pest infestations that details necessary remedial measures for the different collection types and potential pest insects.

Figure 3.5.a: One of hundreds of bird full mounts in the NMSO in Solothurn (photo Thomas Briner)

There are several methods for exterminating pest insects. The measures taken depend on the type of object that is infested and the scale of the outbreak. As there is always a chance that pest insects survive the treatment, it is strongly advisable to first clean and then check the infested specimens after treatment (Petrak 2020). The treated objects should be subsequently included in the long-term monitoring as part of the integrated pest management programme. Here, we describe the preparatory procedures to isolate specimens and prepare them for the treatments described in section 3.3: Treatment by oxygen deprivation (nitrogen environment), biological pest control, freezing and hot-air treatment.

Procedures to follow when detecting infestations

Petrak (2020) provide a step-by-step procedure to follow after detecting an infestation: First, identify pests, i.e. the pest type, life cycle and behaviour. Second, assess the situation on site (climate, general conditions). Third, determine and remedy the cause of the infestation to avoid future outbreaks. Fourth, clean infested areas well and remove dead insect bodies. Fifth, choose an appropriate method for treating the affected objects and the environment. Sixth, take species specific measures if pest insects are detected.

Isolation of local infestations

If a local small infestation has been detected, it can be isolated by removing it from the collection and then treated, for example, by oxygen deprivation (see section 3.3). Ideally, the whole infested area, including a buffer zone, should be removed and treated.

If the infestations are not restricted to a certain area and reach problematic scales, the entire collection should be treated by a specialised company (see section 3.3). Whole collections can be moved to a temporary storage facility or decontamination facility for treatment, while the infested evacuated collection room is decontaminated. Afterwards the disinfested specimens can be returned to the original collection facility.

In collections with a low but persistent background infestation, isolating and treating the collection part-by-part is a strategy that may be used to keep infestations low. However, this method is time consuming and puts the specimens at a high risk of damage due to regular handling and treatment. Furthermore, treated areas are infested again by neighbouring infested areas.

Figure 3.5.1.a: Some mammal skins in the ZMZ in Zürich (photo Dennis Hansen)

Fumigation

In the past, whole collections were fumigated regularly to control pest insect populations. Poisons like phosphine (PH_3) or sulfuryl fluoride (SO_2F_2) gases were used. Since 2017, the use of such products has been prohibited by the EU Regulation No 528/2012 concerning the commercial availability and use of biocidal products (EU 2012). The gases themselves, as well as the residues that are deposited on collection objects, cause severe health problems for those working with contaminated objects (see section 3.3.4).

Biological pest control to keep infestations low

Biological pest control can be a very efficient way to keep pest insect infestations low or even eliminate them. One example is the tiny parasitic wasps of the genus *Trichogramma* that is used to treat moth infestations (Petrak 2020). *Trichogramma* lays its eggs in moth eggs. As the parasite grows and hatches, typically in about 10 days, the host egg is destroyed. *Trichogramma* species can be used against different pest insects, such as the common clothes moth *(Tineola bisselliella)*, dermestid beetles and others. The parasitic wasps only survive as long as there are host insects. A successful treatment takes about 9 weeks and at a room temperature above 15°C. Since the eggs of the parasite can be kept for only 24h in the refrigerator, they have to be distributed in the collection facility immediately upon receipt. This should be repeated three times each week for three weeks (Petrak 2020).

It should be noted that biological pest control is restricted to collections with very low levels of biocide contamination; high background levels of biocides have a toxic effect on the parasitic wasps. Furthermore, when such strategies are implemented, the dead insects must be removed from the collection space, as they can also serve as food for pest insects.

Recommendations

- → identify pests species, life cycle and behaviour
- → assess situation on site (climate, general conditions)
- → identify and eliminate causes of infestation to prevent future outbreaks
- → clean infested areas well and remove any dead insects
- → select a suitable method for handling the infested objects and their environment
- → do not use biological pest control as a sole or primary control measure, since its implementation is relatively difficult compared to other measures

Supplier

- get *Trichogramma* eggs from UFA-Samen Nützlinge (Aesch CH, www.nuetzlinge.ch)

Further reading

- to identify pest insects, consult an expert or see relevant texts, e.g. ÖSV (2019) or www.whatseatingyourcollection.com

3.5.2 Mould infestation treatment

Treatment of mould infestation is not trivial. If moulds are detected Petrak (2020) suggests the following procedure: identify moulds by isolating fungus, for example, by using adhesive strips and send in the sample for analysis, determine and remedy the cause of the infestation, assess the condition of the property, choose an appropriate method for treating the affected object, assess the situation on site (climate, general conditions) and adapt the environment (stable climate, air circulation).

Removing moulds

Moulds can be removed with a special hazardous material vacuum cleaner (equipped with a ULPA-filter (U16) for grains <4–5 micron, ideally 1–2 micron to be sure that spores are also filtered). Alternatively, mould can be cleaned from tainted specimens with diluted ethanol or isopropanol (7 parts plus 3 parts water)) (Petrak 2020, Meier 2006). Further possible detergents are n-propanol and diluted acetic acid or aliphatic hydrocarbons, such as hexane (if the object surfaces are sensitive to organic solvents). Sensitive collection items can also be restored by using a mix of 75% ethanol and 3–5% H_2O_2. This solution presents fewer health and safety concerns than the other solutions mentioned.

It should be kept in mind that different species of moulds and object surfaces need different treatments. Wet cleaning does not kill the mould but removes fruit bodies and spores (Petrak 2020). Nitrogen-chamber treatment does not help against mould infestations as mould can survive with very low oxygen levels which are impractical to reach.

Detect level of mould outbreak

If you are faced with moulds on objects, it is important to measure the degree of infestation. To do this, it is important to consult a specialist. It is possible to measure the number of mould cells using a luminescence test (see von Lerber 2016 to buy or loan a measurement device). There are four categories of infestation: clean, weak, medium and severe infestations (see pictures also in von Lerber 2016). The Lumitester-device, however, measures living and dead cells not only of mould but also bacteria and other contaminants. It is therefore important to evaluate the success of an applied cleaning process and determine if the remaining potentially allergenic and toxic substances have fallen to acceptable levels for humans.

Worker protection

When starting a mould treatment, one should be aware that moulds can also be hazardous to humans (Petrak 2020). Mould can be allergenic, significantly affecting the well-being and health of people who come into contact with it. Therefore, self-protection is of paramount importance when processing objects affected by mould. For very strong infestations, it is important to contact a specialist (von Lerber 2016 describes a procedure for this case). For all other categories, the following procedure is recommended: to avoid health issues, use a laboratory coat with long sleeves that can be washed at 95°C (von Lerber 2016). For the removal of moulds one should wear disposable latex or vinyl gloves (Petrak 2020) or nitrile gloves, and they should be changed every two hours (von Lerber 2016). A protection mask (filter type FFP2 or better FFP3, daily replacement), protection glasses and a protection suit should also be worn (von Lerber 2016, Petrak 2020). Change protection gear within in infested areas. Clean hands and face with a disinfestation detergent. Wash the lab coat after 3–5 days (von Lerber 2016).

Treatment of mould infested objects

If mould infestation is suspected, the infested objects should be isolated so that the mould cannot spread to other close objects or other areas of the collection. If the infested objects are wet or damp, they must be dried. However, be aware that damp mould growth must not be dried too quickly. If it is, it can induce a fast 'panic' reaction

where huge numbers of spores are released that can infest the entire storage facilities (see example at the Überseemuseum in Bremen in the early 2000s). Sometimes, intermediate storage of tainted objects in a freezer is a better option.

Mould on surfaces is usually removed when it is dry by using a hazardous material vacuum cleaner with ULPA filter U16 and a brush attachment for moulds, latex sponge, soft brushes or microfiber cloth. If needed, CTS-Suisse provides a set of micro attachments. If a brush is used, it is recommended to keep a vacuum cleaner next to the brush to vacuum up the spores. When changing the vacuum bag or filter, remove them carefully and seal them directly in a plastic bag to avoid spreading the spores throughout the room during subsequent transport.

For the dry-treatment, it is important to make sure that spores are not stirred up into the air, as this can cause health problems and facilitate the spread of contamination to other collection items. Shelves can be cleaned with 70% ethanol on a microfiber cloth that should be disposed of afterwards. All materials that came into contact with the mould must be disposed of or disinfested after usage. This can be done by thermal sterilisation or disinfection, for example, with alcohol (Meier 2006). The used brushes etc. should be cleaned in 70% ethanol for 10 minutes and ULPA filters and dust bags of the vacuum cleaner must be disposed of (von Lerber 2016). For the frequency with which vacuum filters should be changed, see manufacturer specifications.

If the infested materials are suitable for a moisture treatment, they can be disinfested in a second step with an ethanol-water mixture (70% ethanol in 30% water) or 70% isopropanol.

Mouldy objects can usually only be cleaned superficially and incompletely, since the mould mycelium penetrates the objects themselves. These objects are therefore susceptible to re-infestation, which is why the climatic environment of objects that have been damaged by previous mould infestation must be checked particularly carefully (Huber 2017).

Light mould infestations, caught at an early stage, can often be cleaned, leaving nothing behind that would indicate a mould infestation. Be aware, however, that the danger of a renewed infestation is nevertheless present, since the remaining mycelium can grow again under favourable climatic conditions. If the objects are stored in a stable climate with a relative humidity below 60%, the risk of re-growth can be minimised. If, for any reason, the infested objects cannot be cleaned, the humidity must no longer reach 60% relative humidity, otherwise mould growth could be triggered. Alternatively, dehydration can be carried out at an increased temperature (above 40°C), which prevents growth and stops spore production. Destroying the spores would require far higher temperatures (min. 80°C) that are usually not tolerated by the specimens themselves. Alternatively, the spores can be killed by irradiation with gamma rays.

Taking care of an infestation – an example

In 2017, a larger mould infestation in the collection had to be renovated at the Nature Museum Luzern (Hotz 2020). Objects from all areas of the collection were infested – in botany and geology it was primarily the cardboard storage boxes and wooden drawers, in zoology, the vertebrate specimens (see figure 3.5.2.a) as well as insects and their drawers.

For the cleaning of the objects and the containers, the collections had to be taken to a temporary storage and cleaning location outside the contaminated rooms. External experts were employed for the professional clearance, transport and cleaning. A concept was developed to protect the health of the people involved and to prevent the mould from spreading outside the infested rooms.

Figure 3.5.2.a: Mould on a mounted bird in the NMLU in (Luzern) (photo Benedict Hotz)

The outsourcing and cleaning of the infested parts of the collection was a logistically demanding action with an extensive use of manpower, time and financial resources. The renovation of the contaminated collection rooms was also an expensive and time-consuming task. Thanks to a quick intervention and a professional approach by everyone involved, the damage to the collection was kept to a minimum. In order to avoid getting into such an emergency situation, it is advisable to clarify the properties of the collection rooms before moving collections into them. It is also important to allow any newly installed air-conditioning systems to run in for a sufficient length of time (several months) with appropriate monitoring.

Recommendations

→ store infested objects in a quarantine room, or at least separate them from the rest of the collection, before treatment

→ use personal protective equipment PPE (gloves, protection suit, FFP3 mask) during work with infested materials

Suppliers

- to remove moulds in rooms contact STC Umwelt AG (Kölliken CH, www.stcag.ch)
- get personal protective equipment (PPE) like masks and glasses from Hasler + Co AG (Winterthur CH, www.hasler.ch) or Carl Roth Laborbedarf (Arlesheim CH, www.carlroth.com/ch) or Brady GmbH, Seton Division (Thayngen CH, www.seton.ch) or Sury AG (Zollikofen CH, www.sury.ch)
- get packing material from Rajapack GmbH (Pratteln CH, www.rajapack.ch)
- get hazardous material vacuum cleaners with U16 ULPA-Filters from Nilfisk AG (Stelz CH, https://new.nilfisk.com/de-ch)

Further reading

- get a general overview on mould infestations in standard books on integrated pest management like Appelbaum (2018), Pinniger et al. (2016) or Hilbert (2002)
- for specifics on moulds in heritage collections, see Florian (2004)
- to analyse moulds, see Meider (2016)
- for an example on how to deal with a large-scale mould infestation, see Hotz (2021)

3.6 Special protection of specimens

Specimens are not only potentially harmed by suboptimal climatic conditions and pest infestations but also from damage as a result of handling, shipping and even theft. Moreover, objects can be harmed by contact with fire or water. As such, emergency plans should be developed.

Further reading

- for a thorough discussion on different agents of deterioration, see the web page of the Canadian Conservation Institute (CCI 2020)

3.6.1 Object handling and packing

Handling and transport are the events that place objects at the highest risk of damage. Therefore, proper packing is essential. If objects are packed for transport in a professional way, the rate of damage is lower and the objects themselves are treated better by the loaning institutions and persons handling the loaned material during the loan period.

Packing delicate objects – an example using birds

Moving a collection of large birds exemplifies what should be considered when packing large but delicate objects.

For transportation, skins can be packed in cardboard boxes or in the original drawers, if they have covers. Wrap them individually in tissue paper to prevent cotton from catching on them and then pack them densely, completely surrounding them by heavy cotton or other similar tissue. Boxes should be packed full and with slight pressure so that there will be no settling or shifting of contents. The wooden base of small mounted birds can be fixed with a physical system on the bottom of large cardboard boxes. Special attention should be taken such that tail feathers do not touch other specimens or the sides of the box.

Large mounted birds should be transported like other large mounted specimens, using bands and soft protective material (like Ethafoam) to secure the base and to make sure they do not shift during transport. The protective material should not touch the feathers but rather the platforms (and beaks if needed) or stabilising structures from the preparation process. The heads of large birds, like flamingos or herons, should be securely fixed during transport to prevent stress on the wire within the neck. Plastic wrappers work well in that respect for medium-sized specimens.

Figure 3.6.1.a: Packing eggs for transport at the MHNG in Geneva (photo Philippe Wagneur)

Eggs and other very delicate specimens need extra care. Stuff the drawer with tissue paper or other soft material to prevent the eggs from moving (see figure 3.6.1.a).

Sending pinned insects

Insects are very delicate and shipments by post must be well-prepared. Specimens should be placed in a sturdy box with a lid that closes tightly, and with a pinning bottom made of Plastazote (about 1 cm thick) that will hold the pins securely. Do not use styrofoam as it does not properly secure the specimens. Pin the specimens firmly in the pinning base, leaving enough space between the specimens to facilitate their removal. Heavy or long-bodied specimens need to be secured with bracing pins on each side to prevent them from rotating on their pins during shipment. The box with the specimens is placed in a larger box with 5–10 cm of packing material between the inner and outer box on all sides.

Specimens preserved in liquids

There are several international regulations and guides on the shipment of dangerous goods. Natural history objects preserved in flammable liquids, such as ethanol, fall under this reglulation. However, there is an exception known as the IATA special provision A180 for natural history samples. If samples are properly packed, they are no longer considered as dangerous goods and can be shipped more easily.

First prepare the specimen for shipping: Fill each vial with preservation liquids without any air bubbles. Use only very watertight stoppers. Wrap each vial with cotton, tissue paper or paper towels to prevent shocks between them. For fragile specimens, it may be best to separate the specimen and the label. The label may damage the specimen if it moves too freely during transport. Put the specimen in a smaller vial enclosed in a larger one with the label or pad the label with cotton wool inside the vial with the specimen.

Second prepare the shipping package following the IATA special provision A180. In short: first get a packing tube system for heat sealing. Specimens are placed in vials or other rigid containers with no more than 30 ml of alcohol or an alcohol solution. The vials are then placed in a plastic bag that is then heat-sealed (no zip-lock seals are allowed). The bagged specimens are placed inside another plastic bag containing enough absorbent material to absorb the fluid from all the samples in case of massive leakage, which is then heat-sealed. The finished bag is then placed in a strong outer packaging with suitable cushioning material. The total quantity of flammable liquid per outer packaging must not exceed one litre and the completed package is marked ‘scientific research specimens, not restricted, Special Provision A180 applies’. More detailed instructions are given in SPNHC (2020) and Bentley (2008). A hands-on guide with pictures is provided in Neumann (2017).

Recommendations

→ pack specimens professionally for handling and transport

→ to send specimens in liquids, follow the IATA special provision A180 guidelines

Example

- the SNM (Sammlungszentrum in Affoltern am Albis) has its own packing facility and trained staff

Suppliers

- get upholstery foam as Ethafoam or Mecasoft, bubble wrap and polyethylene (PE) films of different types from Medewo AG (Meisterschwanden CH, www.medewo.ch) or Digipack AG (Wetzikon CH, www.digipack.ch)
- get duct tape for conservation purposes like ScotchTM 3M 244 (gold masking tape, various widths) from Sury AG (Zollikofen CH, www.sury.ch)
- get tailor-made, individual packaging (padded foam) from Büttikofer AG (Wolfhausen CH, www.foampartner.com)
- get plastic containers for storage, safekeeping and transport made of Acrylonitrile butadiene styrene (ABS) like Rako boxes from Utz AG (Bremgarten CH, www.utzgroup.ch)
- get plastic containers for storage made of polyethylene (PE), polypropylene (PP) and above all polystyrene (PS) from Semadeni AG (Ostermundigen CH, www.semadeni.com) or Brac-Werke AG (Breitenbach CH, www.brac.ch)
- get silk tissue paper on a roll from Klug Conservation (Immenstadt DE, www.klug-conservation.de/Seidenpapier-Seidenpapier-mit-Alkalipuffer-auf-Rolle)
- get Tyvek® Soft non-woven polyethylene tissue on a roll for protection in transport and storage from Deffner and Johann (Röthlein DE, www.deffner-johann.de)

Further reading

- for a general overview, see Carter and Walker 1999
- for hands-on guides on packing specimens with a focus on cultural history objects, see Stolow (1987)
- to pack and send vials with preservation liquids according to IATA special provision A180, see Bentley (2008) or SPNHC (2020) and the conference presentation of Neumann (2017)
- to pack insects, see Schauff (1986)

3.6.2 Fire

Fire clearly represents one of the most serious hazards to collections. Biological collections contain much flammable material, for example, a herbarium collection that may include huge quantities and concentrations of paper and dry plant material (see figure 3.3.4.a), a xylarium contains massive pieces and/or volumes of wood (see figure 3.6.2.a) or even alcohol-stored fruits (see section 3.2.4), seeds or flowers (see figure 2.5.2.a).

Figure 3.6.2.a: Representative specimens of the wood collection (xylarium) of the CJBG in Geneva (photo CJBG)

Avoid electric systems causing fires

The risk of fire is strongly associated with electrical systems, which must be checked regularly. Another possible risk of fire is linked to heat sources (i.e. hot plates) that researchers may use to boil water for specimen fragment preparation before dissection, a common practice in herbaria in order to rehydrate material. Such practices should be strictly prohibited from collection spaces. However, they frequently take place in researchers' offices or in visitor facilities, which may be located near the collections. Such operations must be meticulously conducted.

Monitoring during building renovation

Aside from destruction caused by acts of war (for example, the bombing of the Berlin herbarium during WWII) or natural events like earthquakes or flooding, the great majority of serious fires in collections have occurred during renovations to collection rooms (even, ironically, including installation of fire-detection systems!). Clear instructions must be given to those involved in such projects, including the raising of awareness on the value of the collections. Some means of permanent surveillance should be used, especially if work continues for several days. In this case, all machines must be unplugged when left unattended at night.

Isolate highly flammable liquids

Collections in ethanol are considered by the Swiss National Accident Insurance Fund (SUVA, national insurance in charge of worker protection), as storage of highly flammable liquids because pure ethanol has a flashpoint of 13°C and is therefore inferior to the threshold of 30°C. The safety requirements for large quantities (i.e. >100 l) include: storage at a temperature below the flashpoint, compartmentalisation of the different storage areas with fire resistant doors, secure electrical plugs, adequate ventilation system as well as fire detection and extinguishing systems. SUVA requirements are developed mainly for industry and laboratories and must therefore be adapted to scientific collections. Guidelines vary depending on the building, the total quantity of flammable liquids and the sizes of the jars in the collection.

Figure 3.6.2.b: Part of the historic wet collection in a spill proof plastic box in the MHNF in Fribourg (photo Michael Maillard)

Fire detection measures

Fire detection is essential and is generally done using smoke detectors, although heat detectors may also be used. Direct communication with fire emergency services is essential, time being the key factor in controlling a fire. However, during office hours, the possibility of breaking the alarm chain in case of a false alarm is important. As soon as an alarm is set off, all doors must shut automatically (see above) and fire control should start at once. If possible, portable powder fire extinguishers should be used, as their impact on the collection is less severe than that of water (see section 3.6.3). However, if the fire becomes very serious, water is often the quickest and most powerful way to fight the blaze.

The question of whether to install automatic, heat-activated sprinklers is difficult to answer, as their use can be very destructive to collections themselves (see section 3.6.3 on water). The further the collection is from a fire department, the more strongly this option should be considered.

Isolate fires

Architectural design of storage facilities is clearly a major factor in controlling a fire and the speed of its spread. A partitioned space outfitted with firebreaks (fire-doors) is essential. As these firebreaks clearly interfere with circulation of staff and of specimens etc., a good solution is to have mechanical doors that close automatically (even in the absence of electric power, using either gravity or springs) but that are maintained open by electrically controlled magnets which are connected to the security system.

Recommendation

→ store specimens preserved in highly inflammable fluids in separate rooms that are appropriately equipped, including fire extinguishers

Example

- evacuation plans for the staff, as well the of the communication of alarms to technical managers, inside and outside of working hours, is set up at the MNVS in Sion

Further reading

- for recommendations on the storage and handling of highly flammable substances, see SUVA (2020a)
- for a summary on the topic of fire prevention, see Stewart (2018)

3.6.3 Water

In the case of herbarium collections, water can pose a serious risk to the specimens, in particular when water supply pipes are directly installed in the roof of the collection facilities. In most cases, burst pipes are caused by a defective weld and the consequences are dramatic for all the specimens in the affected zone. Other common sources of water damage are related to massive rains that cause flooding and firefighting efforts.

Coping with floor floods

Water that pools on the floor of a collection is also a serious risk. Door sills should be avoided but they may be pre-existing feature in certain buildings, for example, bomb shelter doors may have thresholds several centimetres high. The height of the lowermost specimen-bearing shelves must take this into account. In other words, the height of the lowest shelf should be higher than the height of threshold. Each space delimited by a threshold should have a separate flood detector.

Emergency measures in herbaria

A disaster resulting from a faulty water pipe occurred in one portion of the Harvard University Herbaria in December 2009 (Peters 2014). Remedial measures for the affected specimens included an early estimate of the percentage of water saturation, placement in plastic bags and immediate transfer to a –20°C storage facility (meat or dairy distribution warehouses are often the largest facilities available in a city). The deep freezing of wet herbarium specimens is widely known to quickly stop mould growth and also provides additional time to develop a plan of action. Specimens that were only dampened at the edges were spread out on work surfaces to air dry and then deep frozen. In the case of this particular disaster, the desiccant drying method was weighed against the vacuum freeze-drying method. The latter method was deemed more appropriate, namely because specimens were not stuck together.

Recommendations

→ do not store objects directly on the floor. The lowest shelf should be several centimetres above ground and large specimens should be placed on plastic pallets (see figure 3.6.3.a)

→ raise cabinets on plinths to provide ventilation and protection from minor floods

Example

- water ingress is monitored with three water detectors (water detector HY-WA) in the BNM in Chur. These are located in the entrance area, under bunker windows and close to water pipes. The detectors are connected to the general alarm system of the museum

Supplier

- get water detector HY-WA from Wunderli Electronics AG (Weinfelden CH, www.wue.ch)

Further reading

- for extremely valuable information on the treatment of wet herbarium specimens, see Peters (2014)
- for a summary on the topic of water and water damage, see Tremain (2018)

Figure 3.6.3.a: Orca skull on plastic pallet in the NAAG in Aarau (photo Holger Frick)

3.6.4 Protection of commercially valuable objects

Only a fraction of the objects in natural history collections have a commercial value. Among these are precious stones, meteorites, amber and parts of animals like rhinoceros horns and the feathers of certain birds. All of them require special attention when archiving them in scientific collections because they must be protected from deterioration as well as theft.

As a preventive measure, commercially valuable objects should not be displayed in exhibitions, and if they are only in custom-made alarmed display cases. Curators should be cautious when authorising unknown non-professionals to access the collections. It is strongly advised not to leave first-time visitors alone in the collection room but rather to bring them the specimens in a supervised study room, similar to a reading room in a library, that is outside of the collection space.

Rhino horns

The most famous recent examples of objects stolen from European museums are those of rhinoceros horns that have been taken from mounted specimens in public exhibitions. These horns are subject to world-wide trafficking, mostly fuelled by the market for East Asian traditional medicine. Europol estimates that a single rhinoceros horn can be worth between € 25,000 and € 200,000 on the black market. Most museums have implemented preventative security measures which involce removing rhino horns from the specimen(s) on display and replacing them with replicas. The original horns should be kept in a discreet location within the collections.

Bird feathers

Several cases of theft in the 2000s were carried out by thieves who visited bird collections under the false pretext of conducting personal research. During their time in the collections, they took specimens or individual feathers, either to sell them as fly-fishing lures, in the case of the Natural History Museum (UK) bird collection theft in 2009 (Johnson 2018), or to create a personal raptor feather collection, in the case of a theft in the 2010s in Germany, Austria, and Switzerland. The theft of natural history specimens is thus often linked to their monetary value but may also be motivated by a personal attraction to a specific type of collection.

Amber

Many natural history collections possess amber collections of various sizes. Long-term preservation of amber poses unique challenges. Apart from degradation, risk of theft is also a concern, as there is a burgeoning market for pieces of amber, especially if they contain well-preserved animal or plant remains. As with any collection, a compromise must be reached between accessibility and security.

Meteorites

Meteorites are very rare, scientifically valuable and inspiring objects that have long been commercially valuable (see figure 3.6.4.a). Today, meteorites are mostly acquired by museums for long-term preservation, science and exhibition purposes, by scientific institutions for analyses in on-going scientific projects and by private collectors. In contrast to many other natural science objects, the price of meteorites is commonly given as a price per gram. Individual meteorites are typically cut into slices to increase the ‘collector’s value per gram’. The prices range from unclassified ordinary chondrites from Northwest Africa, available for several hundred Swiss francs per kilogram, to beautiful samples of very rare, historical meteorites (e.g. Mars meteorite ‘Nakhla’ that fell in Egypt 1911) for several hundred Swiss francs per gram. The market for meteorites is relatively small and prices are strongly affected by the rules of supply and demand.

Prices are determined by the type of meteorite (ordinary chondrites versus rare and unique types), the available mass (the smaller the mass, the higher the price), the perceived aesthetic value (e.g. fusion-crusted complete individuals with regmaglypts and flow-lines versus 'ugly' samples), the provenance of samples (e.g. freshly fallen from Central Europe versus Morocco), the weathering (cheap weathered versus expensive fresh) and the history (well-known or even famous versus of unknown origins). Also, samples of known fall events are more expensive than those not associated with particular meteorite falls. In practice, market prices can be evaluated by an internet comparison of the similar meteorites to the one to be purchased. However, estimating the monetary value (e.g. for the purpose of insurance) of a meteorite that is unique and historically important is almost impossible. Much of the trading of meteorites is done over the Internet or from person to person at mineral shows.

Figure 3.6.4.a: Example of a commercially and scientifically valuable object, an iron meteorite from the MHNF in Fribourg (photo Michael Maillard)

Recommendations

→ do not put rhinoceros horns or other valuable objects on display in exhibitions, or only in custom-made alarmed display cases
→ take security measures for the protection of commercially valuable objects
→ do not authorise unknown non-professionals to access the collection without supervision

Examples

- to protect rhinoceros' horns, the MHNG in Geneva posted a sign near the rhinoceros mounts presented in the exhibits to explain that the horns were false and why this was necessary. This was done to reduce the risk of damage to the mount and to raise awareness of illegal trafficking of rhino horns
- to purchase meteorites, get market prices online or check out the world's only yearly show specialising in meteorites in Ensisheim in Alsace (France)

Further reading

- for a summary on the topic see Tremain (2020)

3.6.5 Protection of scientifically valuable objects

Most specimens in natural history collections have a scientific value rather than a monetary one. In biological collections, these are mainly type specimens, voucher specimens of rare or extinct species or those specimens with a particular historic importance because of their association with a particular person, expedition or geographical region. To better protect them, these specimens should be treated slightly differently from others and should be labelled as important by means of a tag or colour-code. For holotype specimens, this is usually a red label (see figure 3.6.5.a). There are also labels for specimens of particular patrimonial value. By labelling them, they can be handled with special caution and are more easily recognised in emergency situations. In case of the latter, the storage location of the most important specimens should also be marked on emergency plans and communicated to the potential evacuators. In the case of cultural assets the protective symbol is a blue shield that is placed on the outside of the storage unit.

Figure 3.6.5.a: Holotype specimen, marked with a red type label in the MHNF in Fribourg (photo Michael Maillard)

Inclusive or exclusive storage

There are discussions as to whether type specimens should be stored separately from the rest of the collection or not (see also section 3.6.6). If stored separately from the more frequently handled reference material, they are less likely to be damaged and will be more accessible for research and potential evacuation (Carter and Walker 1999). If the reference collection is not stored under optimal conditions, storing particularly valuable specimens separately may also represent the possibility to ensure optimal storage conditions for these particularly valuable objects.

However, if all of these valuable objects are consolidated in a small space, a pest infestation or some other kind of disaster can lead to catastrophic losses (Carter and Walker 1999). Therefore, most entomological collections prefer to label type specimens as such but keep them in the general scientific collections.

The degree of protection proposed for a botanical collection may be closely associated to an estimation of its scientific value and to the volume of material that has been identified as representing types. For this reason, types can be stored differently depending on the number of specimens they represent. For example, the several tens of thousands of type specimens of the vascular plants are integrated in the general collection of the CJBG in Geneva. A few historical collections of particularly high value, i.e. comprising an unusually high concentration of types, are kept separately and are made visually distinct by way of the cultural heritage sign, important in rescue procedures. The type collection of hepatics is stored in fireproof metal cabinets as they would be at increased risk of physical damage if stored amongst the general collection as the proportion of types is extremely high.

Recommendation

→ evaluate the needs and available possibilities to determine whether scientifically valuable objects should be stored separately from the general collection or not

Examples

- the types (mostly insects) are integrated in the general collection in the MZL in Lausanne. Each container, including jars, boxes and drawers, is labelled with a red mark to signal the presence of a type
- based on the type and volume of types, the CJBG in Geneva adapts the way types are stored

3.6.6 Emergency plans

Emergency plans are highly recommended. Thorough documentation of the physical placement of each part of the collection is also essential, particularly for the most valuable parts of the collections that should be prioritised in case of an evacuation. The evacuation will most likely be conducted by external people who do not have previous knowledge of the importance of different parts of a collection or of the physical organisation of the collection itself. Any special collections that are deemed to be a specific cultural asset should also be flagged by an immediately visible cultural heritage sign (blue shield).

Emergency exercises can be conducted on a 10-year basis, following the proposed emergency plans. It allows technical and scientific staff to be prepared in case of a disaster, with roles attributed to individual collaborators depending on their knowledge of the collection and their physical capacities, among others.

Figure 3.6.6.a: Isotype specimen with high scientific value for the systematic analysis of the species, archived at the Z+ZT in Zürich (photo Reto Nyffeler)

Evacuate type specimens first

Type specimens should be of the highest priority in an evacuation plan. If they are stored separately from the remaining collection, they can be removed quickly in the case of an emergency and are less likely to be destroyed (Carter and Walker 1999).

However, if type specimens are included among the entire scientific collection, the difficulty of evacuating them increases with the number of specimens present in the whole collection. Priority specimens should therefore be marked in the collection and on the emergency plans. Including types in the entire collection has another advantage: if an emergency is restricted to a certain area of the collection and evacuation is not possible, only a fraction of the type specimens will be destroyed. If type specimens are stored together, this type of emergency could lead to the loss of all type specimens.

Recommendations

- → develop an emergency plan for pest outbreaks and elementary disaster events (present in some cantons already)
- → get in touch with other institutions and establish an emergency planning network
- → get in touch with fire departments and the civil defence unit (i.e. protection of cultural property) and perform drills regularly
- → note the most important objects (including priority levels) on a ground plan and make it available to those that are likely to perform an evacuation
- → ensure that priority specimens/collections are marked with the cultural assets protective symbol (blue shield)

Example

- a large-scale exercise was conducted at the CJBG in Geneva involving a scenario where a fire broke out in a collection storage room and was controlled by the fire department using water. The goal was to conduct a mock evacuation of a series of damaged specimens, including primary triage, preliminary treatment, evaluation of fire/water damage, consideration of different secondary treatments (e.g. freezing) and selection of specimens per treatement type and labelling of specimen lots for future tracking

Further reading

- for a guide on developing an emergency plan, see Dorge and Jones (1999)

3.6.7 Insurance

The value of objects in natural history collections is typically scientific and historic rather than monetary. Obvious exceptions are, of course, minerals like precious stones or metals, and other materials discussed in section 3.6.4. But how can we insure millions of objects that do not have any real market value?

In the case of insuring whole collections or facilities, one solution is to estimate the cost required to repurchase a specimen. In the case of natural history collections, this would be money needed to cover the costs to collect such a specimen again in the field or to buy it from another collection (which is in practice rather difficult or even impossible). Of course, certain specimens, such as those representing protected species or types, are irreplaceable and a substitute could never take the place of the original.

Recommendation

- → estimate the number and average value of your specimens. Evaluate specimens for their scientific, historic and monetary value, respectively

Figure 3.6.7.a: Topas of the NMBE in Bern (photo Lisa Schäublin)

3.7 Worker health

Worker health is an important topic since optimal conditions for conservation are not necessarily optimal conditions for working. Also, many collections host specimens that are harmful to humans, such as radioactive minerals or specimens that are contaminated with toxins used for pest control, as seen in botanical and zoological collections. Although work spaces are not allowed in such potentially toxic environments, curation and restoration work must still be performed in the collections and workers require protection. Threats to worker-health should be evaluated and measures put into place to protect staff.

Further reading

- for an overview on harmful substances in natural history collections and protection measures, see Spiegel et al. (2019)

3.7.1 Geology

Geological objects often consist of different natural rock material and contain different chemical components with varying physical properties. Most rock material, fossils and minerals are easy to handle and can be manipulated without major protective measures. However, certain components of rocks and minerals are toxic and can endanger health or form toxic decay products. Minerals containing uranium or thorium, for example, emit ionising radiation that cannot be perceived directly by humans and that constitutes a significant human health hazard beyond a certain dose. Furthermore, the natural decay of uranium-containing minerals creates, among other things, radon. This radioactive noble gas is also produced outside of geological collections everywhere underground. In poorly or unventilated rooms, especially under ground-level, the radon concentration can reach a concentration that is harmful to health. Other minerals are toxic or may cause tissue damage if inhaled. Therefore, special protective measures are necessary, especially when dealing with toxic, harmful and radioactive materials.

Further threats arise from acids or other chemicals used in determining and sampling minerals. Proper handling and protection equipment are also required here.

Furthermore, improper handling of geological objects can cause injury. Excessive physical strain, e.g. lifting heavy loads, can cause discomfort or injury. Finally, when processing or formatting hand specimens, splinters can cause injury and excessive noise can affect hearing.

Although the protection of workers from accidents and injuries should be a matter of course in all these cases, various laws explicitly prescribe measures like the Radiological Protection Ordinance (RPO 814.501), the Labour Law (ArG, 822.11) and the Federal Law on Accident Insurance (UVG 832.20). The latter for instance, requires employers 'to take all measures to prevent occupational accidents and occupational diseases which, based on experience, are necessary, applicable according to the state of the art and appropriate to the circumstances.'

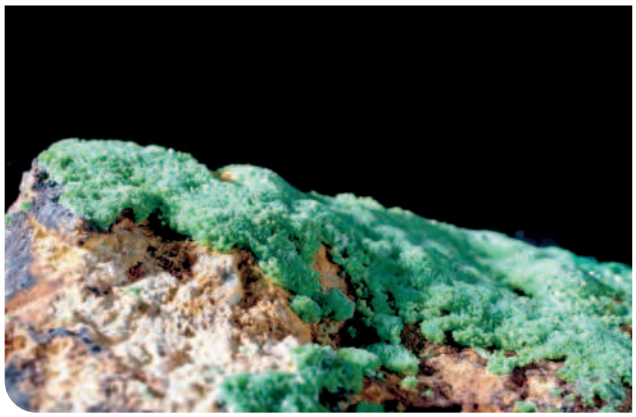

Figure 3.7.1.a: Pyromorphite of the NMBE in Bern which is toxic when ingested or dust is inhaled (photo Lisa Schäublin)

Protection against radioactivity

Minerals containing uranium or thorium emit ionising radiation. The radiation energy released in this way (alpha, beta or gamma radiation) is imperceptible to humans and, beyond a certain dose, is harmful to health. Fortunately, ionising radiation can be measured with a Geiger counter and the radiation sources and levels in the collection can be determined. Following the basic principles of radiation protection will help keep radiation exposure to a minimum. These are: keep overall levels of radioactivity low (e.g. store limited amounts of material); maximise the distance between a source of radiation and collections staff, since radiation power decreases quickly with increasing distance; minimise the length of exposure (limit for people who are not exposed to radiation is 1 mSv per year (RPO 814.501, Art. 22, 56–57); avoid absorption by the body through swallowing (ingestion), intake (inhalation) and absorption through the skin by preventing contact and wearing personal protective equipment (see recommendations); shield the radiation source so that safety thresholds are not exceeded outside the storage space.

According to the Radiological Protection Ordinance (RPO 814.501), the use of ionising radiation is generally subject to authorisation. People who deal with ionising radiation must be trained in radiation protection procedures (RPO 814.501).

With regards to radon, the Radiological Protection Ordinance specifies the level of the reference value for 'rooms in which people regularly spend several hours a day' (RPO 814.501). Levels of naturally occurring radon differ from place to place and the probability of exceeding the reference value varies greatly within Switzerland. Background radon levels are shown on a radon map of Switzerland (FOPH 2020b). The Radon guidance (FOPH 2020c) requires the building owners to take preventive measures with the appropriate technology in order to achieve a radon gas concentration below the reference value. Normally this can be achieved with an efficient ventilation system. If the probability of exceeding the reference value is over 1% and people are in a room that is below-ground (e.g. a basement storage room), a radon measurement is indicated to clarify the effective concentration. Furthermore, elevated radon concentrations can be caused by emanation from uranium containing minerals.

Protection against toxic and other harmful substances

Several minerals are toxic or form toxic decay products and should therefore not be swallowed, inhaled or absorbed through the skin, in particular the common arsenic-rich minerals in collections. Such minerals may be hidden as a matrix, e.g of silver specimens. Asbestiform minerals such as riebeckite (synonym 'crocydolyte'), actinolite ('amiant', 'byssolite'), cummingtonite-grunerite ('amosite') and chrysotile endanger health if they get into the lungs (SUVA 2019). Therefore, such materials must be labelled and appropriate measures taken to prevent inhalation, ingestion and absorption through the skin. In addition to storing such materials in specially marked and closed containers, it is appropriate to wear personal protective equipment (protective mask type FFP3, disposable rubber gloves, possibly disposable protective suits) when handling them.

Protection against physical injury

According to the Swiss accident insurance company SUVA, excessive physical strain is one of the most common reasons for complaints about the musculoskeletal system (SUVA 2020b). The guidance to Regulation 3 of the Labor Act lists the reasonable weight loads for loads carried close to the body as follows: Men between 16 and 25 kg, women between 10 and 15 kg (depending on age, ArGV 3, Art 25). SUVA recommends handling loads intelligently and using suitable aids. These aids can be mechanical forklifts or pallet trolleys for heavy stones. Taking into account the above reasonable load weights, heavy loads can also be carried by several people. When formatting and working on rocks, work gloves and safety glasses, and possibly also hearing protection, are highly recommended.

Figure 3.7.1.b: Palaeontological collection of the NMB in Basel (photo Basil Thüring)

Recommendations

- → procure personal protective equipment like safety glasses, suitable protective masks type FFP3, disposable rubber gloves, disposable protective suits, hearing protection, work gloves and safety work shoes for heavy work
- → purchase a Geiger counter and determine radioactive materials in the collection
- → store and label toxic and harmful materials, especially radioactive ones, properly
- → have the radon concentration measured in the collection rooms and possibly rehabilitate them according to federal regulations
- → obtain forklifts and pallet trolleys for heavy loads
- → do not lift heavy pieces alone, use a forklift or pallet trolley
- → wear safety work shoes when handling the pallet trolley
- → wear gloves and safety glasses and possibly hearing protection when formatting and processing rocks

Examples

- when handling toxic or radioactive minerals and a mechanical forklift for heavy loads, personal protective equipment is used at the NMLU in Luzern. The earth science conservator has completed a SUVA radiation protection course and is responsible for radiation protection at the museum
- radon measurements were carried out in the geological collection of the NMWIN in Winterthur

Suppliers

- for personal protective equipment, see Sury AG (Zollikofen CH, www.sury.ch)
- for measuring equipment such as Geiger counters, see Conrad Electronic AG (Wollerau CH, www.conrad.ch)
- for different dealers, for forklifts and pallet trolleys, see www.logistikkatalog.ch

Further reading

- the Federal Office of Public Health publishes a list of the cantonal radon contact points and for the recognised radon measuring points, see FOPH (2020a)

3.7.2 Botany

Historical botanical collections, particularly those started in the 19th century, were disinfested by means of painting them with mercuric chloride solution before mounting. Many historical specimens stored in Swiss herbaria are marked with a stamp of a skull and crossbones on the label or the sheet. However, many mercury-treated specimens were probably not systematically stamped. This method was used until the early 1980's in large herbaria from North and South America, Africa and Asia. Surprisingly it was recommended for the treatment of herbarium specimens as recently as 1981 (see Hall 1988).

It is now widely known that the use of mercuric chloride to treat specimens represents a health hazard (cases of sterility in women have been reported from certain herbaria) and its use is currently forbidden (see section 3.3.4). Material that has been treated with mercuric chloride remains dangerous for the herbarium users, including curators, technical staff and scientific visitors. They can breathe in toxic vapour or come into direct contact with poisoned specimens when handling them. In the first case, studies have shown clear evidence that increased ventilation in collection storage areas reduced the concentration of mercury vapour, thus rendering the air safer. In the case of direct manipulation of poisoned herbarium specimens, the simple practice of hand washing with soap after manipulation of specimens should be mandatory for any user of the herbarium. Alternatively, vinyl gloves can be used when large volumes of specimens are handled if specimens are moved or reorganised. Other persistent components frequently used for specimen preservation include powder insecticides, as well as naphthalene balls (see section 3.3.4).

Figure 3.7.2.a: Historical lichen collection stored in a drawer in the NMSG in St. Gallen (photo Chris Mansfield)

Protection against physical injuries
Certain safety requirements should be taken into account when choosing ladders to access upper shelves. They should be stable, with handrails and a small work platform at the top of the ladder on which to temporarily place specimens while filing. Handling herbarium piles of 1–5 kg is not a problem if only done once in a while. However, it can become dangerous or harmful if performed repeatedly or improperly.

Recommendations

- → check herbarium sheets for the type and concentrations of poisons in order to protect the health of personnel working in the collections
- → install air-conditioning to protect workers and for favourable specimen conservation
- → wash your hands well with soap after manipulating specimens

3.7.3 Zoology

Various poisons have been used until well into the present day to ward off insect pests. Such poisons form insoluble compounds with objects and are long-lasting, even detectable in the dust in collection spaces. In addition to the products generally known in natural history collections, such as arsenic (various compounds) and mercury (II) chloride, residues of DDT, lindane, paradichlorobenzene, methyl bromide, and naphthalene, as well as more recently developed but no less dangerous agents, like products from the Eulan and Mitin groups, are found. The individual products were sometimes used in very high doses, depending on the level of training of the person applying the treatment.

The use of all these products is now prohibited under the EU Biocide Regulation (EU 2012), especially in the field of natural history collections. Nevertheless, the substances remain on and in the objects in collections. For this reason, collection rooms should not be used as work rooms. When working with objects, personal protective equipment (PPE) must be worn, which is adapted to the scope of the work (for example, the time spent working in the collections, amount of material handled, estimated or known degree of contamination of the specimens).

For simple, short-term, non-dust-intensive work, normal work clothing, FFP2 breathing mask, nitrile gloves and possibly safety goggles are sufficient. Simple work is defined as the removal of a single small object (e.g. a crow). For jobs lasting longer than one hour per day or particularly dusty jobs, such as fetching large objects, normal work clothing should be replaced with Tyvek® gowns. If the work is even more intensive, such as moving objects, the Tyvek® gown should be replaced by a Tyvek® full-body overall or a SUPRA Chemical protective Clothing Type 5+6 and the work should be carried out with a mask with oxygen supply instead of an FFP2 breathing mask.

If an object is transported within the facility, it must be covered or placed in a closed container. Objects treated with biocides may not be displayed in an open display within the exhibitions. As much dust is stirred up during room cleaning, cleaning personnel must be equipped with a Tyvek® full-body overall or SUPRA Chemical protective Clothing, nitrile gloves, FFP2 respiratory mask with exhalation valve and safety goggles. The vacuum cleaners used must be designated as hazardous material vacuum cleaners of ULPA filter class U16. Cleaning personnel must be sensitised and trained with regard to biocide contamination.

Recommendations

- → wear suitable protective equipment during handling, like disposable nitrile gloves, FFP2 dust protection masks or for longer tasks a mask with oxygen supply or FFP2 respiratory protection mask with an exhalation valve and a Tyvek® disposable apron or Tyvek® full body cover or SUPRA Chemical protective Clothing Type 5+6 (Model Supra Best 5201/5202)
- → do not work in collection storage rooms
- → transport objects covered or in closed containers only
- → work with objects only in clearly defined work areas
- → exhibit objects that are contaminated with biocides only in closed display cases
- → mark objects that are contaminated with biocides (danger symbols: danger 'skull', health hazard)
- → wear nitrile gloves/wash hands immediately after contact with specimens
- → only include uncontaminated objects in didactic collections, especially if they are openly exposed. Contaminated objects can be kept in display cases/plexiglass covers

Figure 3.7.3.a: Hunting scene with polecats attacking brown owls from the Challande collection of the early 19th century stored at the NMWIN in Winterthur (photo Daniel Schaffner)

Suppliers

- get display cases or plexiglass covers from Bauer Handels GmbH (Fehraltorf CH, www.taxidermy.ch) or from Semadeni AG (Ostermundigen CH; www.semadeni.com)
- get Nitril gloves from Semadeni AG
- get 'hazardous material' labels from Brady GmbH, Seton Division (Thayngen CH, www.seton.ch)
- get hazardous material vacuum cleaners with U16 ULPA-Filter from Nilfisk AG (Stelz CH, https://new.nilfisk.com/de-ch)
- get FFP2 masks from Carl Roth Laborbedarf (Arlesheim CH, www.carlroth.com/ch)
- get Tyvek® aprons and overalls from Carl Roth Laborbedarf (Arlesheim CH, www.carlroth.com/ch)
- get SUPRA Chemical Protective clothing from Copedia AG (Münchenstein CH, www.copedia.ch)
- for consultations contact Präparatorium Christoph Meier (Münsingen CH, www.präparatorium.ch), Alwin Probst (Naturhistorisches Museum Basel) or Martin Troxler (Naturhistorisches Museum Bern)

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Notes


Coll. P. Zaugg


ycaenidae: Polyommatinae:
olyommatini
Polyommatus damon
Denis & Schiff müller, 1775)


Lycaenidae: Polyommatinae:
Polyommatini
Polyommatus damon
(Denis & Schiffermüller, 1775)
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Chapter 4: Databasing, digitisation and data storage

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4.1 Introduction

Natural history collections around the world share a common vision of open access digital catalogues and databases of their objects, as well as unrestricted use of their data, a vision that is unconstrained by geographical distances, overburdened staff or limited financial resources. In an age where data is an important commodity, natural history collections will play a pivotal role in future collaborations with stakeholders in science, economy and society as well as in finding solutions to global problems such as climate change, biodiversity loss and sustainable agriculture (Schindel and Cook 2018).

In a study conducted by the University of California, for instance, data from 1.4 million herbarium sheets were integrated from collections worldwide and complemented by genetic sequence data available on GenBank to investigate spatial patterns of biodiversity (Thornhill et al. 2017). In global health related research, studying host parasite relationships in specimens stored at natural history collections would significantly improve proactive responses to pandemics, such as the Covid-19 pandemic (Cook et al. 2020).

By uncoupling and mobilising specimen information from paper labels, herbarium sheets and field notebooks, digitisation allows small or regional collections to contribute to international studies, an activity usually associated with larger museums. For countries with a fragmented landscape of collection infrastructure, like Switzerland, digitising natural history collections carries a special significance as otherwise taxonomists and scientists need to physically visit a multitude of different institutions for their studies.

Towards integrated global data infrastructures

Over the past ten years, several national and international programmes for the digitisation of natural history collections were initiated, most notably iDigBio (Integrated Digitized Biocollections) in the United States, and the recently launched European Strategy Forum on Research Infrastructures (ESFRI) Distributed System of Scientific Collections (DiSSCo) in Europe. These initiatives facilitate collaborations with and between museums to build research infrastructure for the integration of specimen data across multiple institutions as well as fostering the adoption and implementation of standards and best practices (Hardisty et al. 2020).

In parallel, thematic databases have begun to centralise digitised information on a global level and have become the central information hubs for biodiversity research. Biodiversity Heritage Library (BHL), for instance, provides access to biodiversity-based literature. The Global Biodiversity Information Facility (GBIF) offers 1.4 billion occurrence records from organisms representing all biological kingdoms; these data originated from natural history collections and from observations by citizen scientists. GBIF sourced data has been recently used in more than 700 peer-reviewed research articles per year (GBIF Secretariat 2019).

In the domain of geodiversity, digital transformation is still lagging. The need for readily available data from Earth science collections, however, has been clearly recognised, as, for example, in studies on soil degradation, the role of peat bogs as carbon sinks and in the discovery of mining sites for industry (Webber et al. 2006; GeoCASe [Geosciences Collection Access Services]).

Efforts to date

Although digitisation initiatives have been gaining momentum in recent years, the proportion of databased specimen records is still low. A mere 10% of all collection objects in Europe have been digitally catalogued (Hardisty et al. 2020) whereas this estimation is slightly higher, at an estimated 17%, in Switzerland (Beer et al. 2019). Most of the larger collections in Switzerland began databasing their collections many years ago. The sheer volume of their holdings, however, necessitates industrial-scale methods that, in many institutions, still await implementation. Smaller museums, in contrast, often lack experienced personnel and the resources necessary for capturing, storing and publishing data in the first place.

Taking the next steps

With around 350,000 type specimens and an estimated 60 million natural history objects, Switzerland features an outstanding wealth of collection holdings, especially considering the size and history of this landlocked country (Agosti et al. 2003; Beer et al. 2019). To assure maximum visibility and utility of these treasures, Swiss natural history collections must first implement high-throughput digitisation procedures, whenever possible, and align their efforts with other institutions for maximum efficiency. Furthermore, all standards, best practices and systems implemented should follow international norms as closely as possible. This will guarantee interoperability with

Figure 4.1.a: Cowries at the NMBE in Bern (photo Lisa Schäublin)

global data and data infrastructures and, in the long run, will greatly facilitate the involvement of Swiss institutions in international research initiatives.

Further reading

- for a concise and up-to-date overview of worldwide data mobilisation, see Nelson and Ellis (2019)
- for general considerations on inventories in museums, see VMS (2007)

4.1.1 Mass digitisation

The term 'digitisation' may be broadly applied to different practices of digitally recording information, all of which seek to database information associated with specimens in natural history collections. Digitally recording information and updating data is an ongoing process, as taxonomic classifications change over time and as additional information, such as genetic sequence data, are linked to the original specimen data.

At a basic level, digital catalogues of collection holdings include minimal records of specimen information, mainly deriving from labels in collection drawers, jars or boxes, and a unique identifier per specimen. The latter allows the specimen to be unambiguously identified on an institutional or even global level. At a more advanced level, information from individual specimen labels is recorded such as collection date, location and collector. Finally, data may be enriched with supplementary information from third-party sources (e.g. genetic sequences). In recent years, a standard on the minimum information about a digital specimen (MIDS) has been developed (Hardisty 2019). It should harmonise the information to be expected from each level of digitisation.

Digitisation is resource intensive and requires collection managers to prioritise tasks as well as to set standards for data quality and precision. There have been lengthy debates on whether digitisation should generate limited amounts of extremely detailed data geared toward specific research questions, or rather extensive amounts of less detailed data that may serve as the basis for new research questions (Scoble and Bourgoin 2010). There is no final answer to this issue but one thing is certain: regardless of the level of detail, digitised data should be openly accessible, under all circumstances. It is impossible to anticipate all possible applications of such data and even the simplest set of data may be useful in some research setting.

Digitisation may be done in various ways. In many collections, data are manually transcribed directly from specimen labels into a spreadsheet or a database. This approach is easy to implement and can be started almost immediately. If more extensive collection holdings are to be da-

Figure 4.1.1.a: Imaging station at the ETHZ-ENT in Zürich (photo ETHZ-BIB/Pierre Kellenberger)

tabased, however, technology and streamlined processes allow for higher data-capture efficiency. In the following sections, a few common strategies will be presented (for detailed information see section 4.7.3).

Division of labour

Dividing labour-intensive processes into a series of shorter tasks will allow employees to develop special skills. Furthermore, steps requiring expert knowledge, such as pre-sorting or categorisation of collection holdings, should be separated from repetitive work requiring low levels of expertise, like data entry or operating a scanner or camera (see figure 4.1.1.a). This strategy might necessitate additional measures for quality control, but overall will save costs and help experts to focus on more specialised tasks.

Prioritisation

It is advisable to begin by defining the units that will be digitised (for further information on unit levels, see section 4.7). For example, units can be sections in a collection, whole shelves, drawers filled with objects or single specimens. Digitising different sections of the collection at different unit levels will allow relevant goals to be reached within realistic periods of time. A reasonable strategy could be the following: The whole collection is databased at the storage unit level, i.e. insect drawers, boxes with herbarium sheets, bags with seed samples or specimens in other types of storage containers. In addition, digitisation at the object level is done for a carefully chosen subset of all specimens, which will differ from institution to institution. This choice is often done by collection managers who select parts of the collection of particular importance for the institution (for example, types, historical collections, or collections from a particular region or taxonomic group) or collections that are needed for a specific purpose (e.g. specimens that will be used in a planned research project).

Imaging

Imaging plays an important role in digitisation. It is a means of capturing the details of collection holdings, such as morphological features of specimens and labels. However, at this point the label is only shown as an image, and if not manually transcribed or analysed by optical character recognition and other machine learning methods, it is impossible to search for the information contained therein in an efficient way. If used reasonably,

however, imaging can enhance digitisation considerably, as is shown in the following cases.

Capturing label data

Label data can be entered into a database directly from the specimen, or, if the specimen has been photographed or scanned, from a digital image of the label. By having taken photos of specimen labels, data entry can be performed with both hands and without handling (and potentially damaging) the specimen. When images of the labels are associated with the specimen in the database, users can consult an image of the original label and verify the transcription. In the long run, label images will be of increasing usefulness as machine learning and other artificial intelligence approaches can glean information from these labels.

Capturing morphological details

Stacked imaging, 3D-scanning and other high-resolution imaging techniques generate virtual representations of specimens, which allow for detailed morphological observations without physical access to specimens. These procedures are mostly done for type specimens or exemplars in reference collections as they provide illustrative material for taxonomists and those developing taxonomic expertise. Because of long processing times, these technologies can slow down the overall digitisation procedure and should be used sparingly.

Mass imaging of collections

If imaging devices are integrated into automated processes, specimens can be databased at high throughput. In herbaria, so-called 'digistreets', which use conveyor belts (see figure 4.1.1.b) and automated scanning stations, have proved highly efficient (also available for molluscs, wet collections, insects, wood samples, dry vertebrates (of appropriate size), microscopic slides, objects from Earth science collections and text documents or illustrations). Another example are whole-drawer scanning systems for insect drawers: A camera on a robotic arm takes multiple photos of an entire drawer and pieces them together to create one final, high-resolution image.

Recommendations

- → digitise the collection unit level first, capture metadata on the storage unit level and then focus on the most relevant curatorial units ('objects')
- → images are ideal for documenting original label data but should be used when documenting morphological details of specimens (using specialised 3D scans, for example) only when necessary
- → division of labour will increase specialisation and helps experts to focus on specialised tasks
- → use persistent identifiers (see section 4.2.2) in the collection management system to facilitate data exchange both nationally and internationally

Examples

- the Naturalis Biodiversity Center in Leiden, Netherlands, is one of the world's largest natural history museums. Between 2011 and 2015, the museum digitised their entire collection of more than 37 million objects on a storage unit level. Of those, seven

Figure 4.1.1.b: Mass imaging of herbarium sheets on a conveyor belt done by the company Picturae at the CJBG in Geneva (photo CJBG)

million objects were databased in more detail on an object unit level (van Oever and Gofferje 2012)
- the Musées et Jardins Botaniques cantonaux in Lausanne outsourced the digitisation of their 120,000 herbarium sheets to the company Picturae. By using 'digistreets' and streamlined processes up to 5000 specimens were databased per day and the whole project was finished within two months (L'herbier vaudois 2.0)

Supplier
- massdigitisation with conveyor belts is provided by Picturae (Heerhugowaard NL, https://picturae.com)

Further reading
- for an overview of industrial scale digitisation in natural history collections, see Blagoderov et al. (2012)
- for an overview of whole-drawer imaging technology in entomological collections, see Holovachov et al. (2014)
- for state-of-the-art herbarium digitisation workflow, see Nieva de la Hidalga et al. (2020)
- for a short introduction on mass digitisation, see Beaman and Cellinese (2012)

4.1.2 The FAIR data principles

To be of maximum benefit to research and society, data management should follow core principles that meet the standards of findability, accessibility, interoperability, and reusability ('FAIR', Wilkinson et al. 2016). The FAIR data principles are written in a very general form to allow for maximum applicability, as can be seen in figure 4.1.2.a.

Defined in 2016 by an international team of scientists, the FAIR Guiding Principles are increasingly consulted when setting up research infrastructures for natural history collections. Information about natural history specimens and collections may be found in publicly accessible and searchable indexes. If not protected by third party rights, nature conservation regulations or international multilateral environmental agreements, natural history collection data should be freely accessible to everyone. To guarantee data interoperability, common formats (data standards) that allow for data exchange between systems are essential (Hardisty 2019). Controlled vocabularies and ontologies facilitate a shared understanding of the context of the data and multiple organisations should agree upon common policies, principles and working procedures for digitisation. Finally, data that is accessible and without restrictions should be usable for all purposes.

Recommendations

→ collection holdings should be digitised as extensively as possible
→ data should be as accessible as possible and as inaccessible as legally necessary
→ best practice recommendations on the digitisation and data management of natural history collections should be followed
→ data should be released by using copyright waiver such as CC0 or an open access licence such as CC-BY

Further reading
- for the FAIR Guiding Principles for scientific data management and stewardship, see Wilkinson et al. (2016)
- similar to the FAIR data principles, the Linked Open Data principles (by Berners-Lee 2009) aim at enabling data driven science. For a comparison of the two principles, see Hasnain and Rebholz-Schumann (2018)

The FAIR Guiding Principles

To be Findable:
F1. (meta)data are assigned a globally unique and persistent identifier
F2. data are described with rich metadata (defined by R1 below)
F3. metadata clearly and explicitly include the identifier of the data it describes
F4. (meta)data are registered or indexed in a searchable resource

To be Accessible:
A1. (meta)data are retrievable by their identifier using a standardised communications protocol
A1.1. the protocol is open, free, and universally implementable
A1.2. the protocol allows for an authentication and authorisation procedure, where necessary
A2. metadata are accessible, even when the data are no longer available

To be Interoperable:
I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.
I2. (meta)data use vocabularies that follow FAIR principles
I3. (meta)data include qualified references to other (meta)data

To be Reusable:
R1. meta(data) are richly described with a plurality of accurate and relevant attributes
R1.1. (meta)data are released with a clear and accessible data usage license
R1.2. (meta)data are associated with detailed provenance
R1.3. (meta)data meet domain-relevant community standards

Figure 4.1.2.a: The FAIR Guiding Principles (from: Wilkinson et al. 2016)

4.2 Identification of objects and data

4.2.1 Catalogue numbers

Natural history collections have been using numbering systems for organising and referencing collection specimens for centuries. Initially, these numbering systems were often unique only within groups of specimens corresponding to particular taxa (e.g. beetles), geographic areas (e.g. Palearctic realm) or donated collections. With the advent of massive cataloguing and digitising initiatives, institutions began to use consistent systems for the application of catalogue numbers to all of their specimens (see figure 4.2.1.a).

Catalogue numbers should be unique within the respective collection or institution. To avoid ambiguities with identical numbers used in other collections or institutions, catalogue numbers are often combined with institution codes and collection codes to remain unique on a global scale. Institution codes and collection codes are frequently registered at the GBIF registry, which is a clearinghouse of information about object-based scientific collections (further information in section 4.7.4). These identifiers are also called 'Darwin Core triplets'. The ETH Entomological Collection, for example, uses a 7-digit numbering system for its two million specimens, which is preceded by the institution code 'ETHZ' and the collection code 'ENT': ETHZ-ENT1234567. Although not centrally registered, these identifiers are usually referenced outside of the parent collection, for example in publications.

Figure 4.2.1.a: Unique catalogue numbers in the mollusc collection of the NMBE in Bern (photo Estée Bochud)

Recommendations

- → catalogue numbers should be unique
- → to avoid ambiguities among numbers from different institutions and collections, catalogue numbers are often used in combination with institution codes and collection codes

Further reading

- for background information, see Society for the Preservation of Natural History Collections (SPNHC) Thread on 'Numbering Natural History Collections' (https://spnhc.biowikifarm.net/wiki/Numbering_Natural_History_Collections)

4.2.2 Persistent identifiers (PIDs)

As digitisation initiatives gain momentum, an unambiguous means of referencing specimens and their associated data becomes increasingly important on a global scale. Catalogue numbers can be unique, as described in the section above, but there is no global standard format or control for their 'uniqueness' and thus a system of globally accepted identifiers should resolve the organisation of them and the referencing to specimens among institutions worldwide. In recent decades, different systems of persistent identifiers have been set up, all of which allow unique and long-lasting referencing to digital (documents, websites, files, etc.) or physical objects. The persistence of these identifiers is mainly a function of humans and organisation, and to a lesser extent of technology. To guarantee global uniqueness, identifiers can either be organised in a central registry or, alternatively, be generated in a way that minimises duplication. In addition, they can be opaque or transparent as explained below.

Figure 4.2.2.a: Parasitic wasps at the NML in Luzern (photo Gerry Nitsch)

Identifiers without centralised registry

One of the most frequently used systems of generating unique identifiers without a centralised registry is the Universally Unique Identifier UUID. It is a 128-bit number that anyone can generate locally. The probability of duplicating a code already taken is near zero. A UUID might look as follows: 123e4567-e89b-12d3-a456-426655440000.

Identifiers with centralised registry

Today, many different schemata of persistent identifiers with centralised registry exist worldwide such as URN, ARK or PURL. The most widely used identifier for digital objects in science is the Digital Object Identifier DOI proposed by the International DOI Foundation (IDF, Brase et al. 2009). DOIs can only be assigned by official DOI registration agencies. In Switzerland, these agencies are the ETH Library and CERN. DOIs are identifiers in the Handle System with the general form NN.prefix/suffix. In case of DOIs, NN is always 10. A natural history specimen from a dataset at the data repository Zenodo might have the following DOI: 10.5281/zenodo.1492063.

Opaque identifiers

In the context of identifiers, the term 'opaque' is used if an identifier provides no information about the object it identifies but is just a random sequence of letters and numbers. UUIDs, for example, are opaque identifiers. The lack of human-decipherable information can make opaque identifiers difficult to use as they provide no clues about the object itself or on the parent institution of the specimen. Yet human readable information, as inherent to transparent identifiers, may undergo changes over time and this may increase the likelihood that the identifier will be changed and thus lose its persistence.

Transparent identifiers

Transparent identifiers partly or wholly consist of human-decipherable text or human-meaningful strings. In Europe for example, the Consortium of European Taxonomic Facilities, CETAF has set up a common system of HTTP-URI – based stable identifiers to refer to physical collection specimens (see figure 4.2.2.b). It is gaining popularity as it allows institutions to generate their own unique stable identifiers. Furthermore, it links the catalogue number or object name used within the institution with a globally unique domain and does not require a centralised registry system (Güntsch et al. 2017). Human users can glean a considerable amount of information about a specimen and parent institution from such an HTTP-URI based identifier. This transparency, however, represents drawbacks, as it may make certain changes difficult to accommodate. Transferring specimens to other institutions, for example, would require a re-direct to the new domain to be put in place or some alternative technical solution (Poelen 2019).

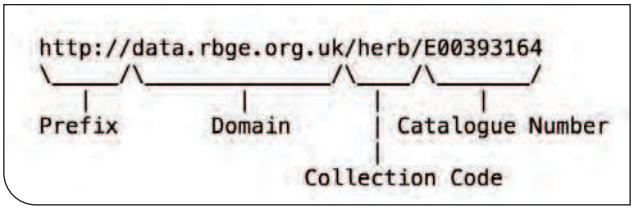

Figure 4.2.2.b: Example of a Unique Resource Identifier (URI) linked to a physical object, in this case a herbarium specimen at the Royal Botanic Garden Edinburgh with the catalogue number E00393164

Recommendations

→ assign persistent, unique identifiers to all specimens in a collection using one of the above cited services

→ use Digitial Object Identifiers DOI for digital objects such as specimen images. Although the distinction between the physical object and its associated digital resources is occasionally omitted, the use of different identifiers for different entities it is a prerequisite for a consistent system

Examples

- the European research infrastructure DiSSCo is planning to create a new persistent identifier called Natural Science Identifier or NSId (Hardisty 2019) via a registry that will mint, store and resolve the identifiers. An NSId is an identifier intended to centralise persistent identifiers, as well as all other identifiers, to associated digital resources and further data assets in the emerging global network of digital objects via the Internet. This includes, for example, all published journal articles identified by DOIs. In other words, an NSId is an identifier that organises all identifiers for a given specimen. NSIds will be identifiers in the Handle System with a specific DiSSCo top-level, which are the first two numbers of the identifier
- since 2017, the System for Earth Sample Registration (SESAR) is the global registry for specimens from the Earth Sciences, assigning International Geo Sample Numbers (IGSN)

Supplier

- the 'ETH Zurich DOI Desk' is the official DOI registration office for Switzerland's university and research sector

Further reading

- for a discussion of persistent identifiers in herbarium specimens, see Nelson et al. (2019)
- for information on HTTP-URI based stable identifiers in natural history collections, see Güntsch et al. (2017)

4.2.3 Barcodes

Barcodes in the present context are visual and machine-readable representations of data. Barcodes can encode any kind of information, for example catalogue numbers, shelf numbers or taxonomic names. In natural history collections, barcodes are widely used in facilitating the organisation and digitisation of specimens: The application of barcodes together with corresponding barcode readers or computers can significantly accelerate data acquisition and reduce error rates as data can be retrieved easily. If captured on images in mass digitisation, for instance, computers can automatically read unique identifiers and species names into the database.

Barcodes exist in one-dimensional and two-dimensional form. One-dimensional barcodes represent data by varying spacings and widths of parallel lines. In two-dimensional or matrix barcodes, black, white and, more recently, coloured cells are arranged in an area, for example a square or a rectangle. Barcodes can appear alone but frequently the content encrypted in the barcode is reproduced in human-readable characters and appears next to the barcode to account for situations when a barcode reader is not available or if a barcode was to become unreadable (see figure 4.2.3.a). Collection personnel can easily convert data to barcodes using a growing number of software solutions. In the case of persistent identifiers, which are usually required in large numbers, ordering pre-printed labels or stickers from commercial vendors can save time and money.

Figure 4.2.3.a: GBIF label, both as a Matrix and in a human-readable representation (photo Pascal Tschudin)

Recommendations

- → in large collections, encoding information as bar-codes will facilitate automatisation (e.g. on convey-or belts for specimen imaging)
- → consider purchasing pre-printed barcode labels or stickers, if possible

Suppliers

- for professional barcoding products and services contact Strico AG (Fehraltorf CH, www.strico.ch) or Electronic Imaging Materials Inc. (Keene US, www.barcode-labels.com)

Further reading

- for detailed information on the use of barcodes in natural history collections, see iDigBio (2016)
- the application of barcodes in digitisation can be seen here: www.youtube.com/watch?v=2R2QGzHIoWE

4.3 Data standards for the exchange of collection data

With the advent of massive digitisation programs and mobilisation of natural history collections data, the need to share collection data easily and unambiguously within the scientific community and with the general public worldwide, as well as to retrieve data and exchange information between diverse database systems, has intensified. To this end, two main data exchange standards for natural history data, Darwin Core and ABCD (Access to Biological Collection Data), have been developed in the past decades, which define rules for describing, recording and exchanging data. Services and networks like GBIF (Global Biodiversity Information Facility), BioCASe (Biological Collection Access Service), GeoCASe (Geosciences Collection Access Services), OpenUp (Opening Up the Natural History Heritage for Europeana) and iDigBio (Integrated Digitized Biocollections) have made significant progress in this regard. In these networks, locally hosted databases of different types and structures must be able to communicate with one another.

Data Exchange Standards, also known as Metadata Standards, are rules for recording, describing and exchanging data. These standards ensure that data structures among various institutions are always interpreted and mapped correctly and that data is understandable and unambiguous. Database fields that refer to a single concept may still have different names in different collections. For example, *Collection Number, FieldNr, CollNr, NMBE_Nr, NR_Catalogue* and *ObjNr* are database field titles used by different institutions that all refer to the unique identifier assigned to an object. Likewise, datebase field formats may differ considerably between databases. Different date formats, for example, such as *22.02.2020, 2020.02.22, 22_2_20 or 22. February 2020* must be interpreted correctly, irrespective of the database structure or location of the respective collection. A key requirement for seamless and error-free data exchange among collections is therefore the unambiguous definition of data field names and standard formats for data fields containing identical content. Furthermore, communication among collections and their databases is made easier if the same organisms or minerals are named in exactly the same way by using common vocabularies (taxonomies) or if linked to an external, persistent and unequivocal identifier.

Figure 4.3.a: Labelled jars in the wet vertebrate collection of the MHNG in Geneva (photo Philippe Wagneur)

Two main data exchange standards exist within the context of natural history collections: the Darwin Core standard (DwC), originally developed in the United States, and the Access to Biological Collection Data schema (ABCD; optionally Extended For Geosciences, ABCDEFG) in Europe. The development of both standards started around the turn of the millennium and both have been approved by the Biodiversity Information Standards association (formerly known as the Taxonomic Databases Working Group, TDWG), in the meantime.

The purpose of the two standards was the promotion and exchange of biodiversity information. Although they were developed at around the same time, the philosophies behind them were different. Darwin Core was mainly intended for the registration and exchange of biodiversity data, not necessarily for data from natural history collections, and the philosophy was to keep the standard as simple and open as possible (Wieczorek et al. 2012). In contrast, ABCDEFG was intended to become an exchange standard optimised for the rich specimen data from natural history collections and was thus more extensive and structured (Holetschek et al. 2012). Over the last two decades, however, Darwin Core has added extensions to broaden its scope and the two standards have begun to converge. Efforts to combine Darwin Core and ABCDEFG started in 2019 and will hopefully result in a single, unified standard in the not too distant future.

4.3.1 Dublin Core Metadata Initiative

The Dublin Core metadata standard represents the conceptual base for standards like Darwin Core (DwC) and ABCDEFG. It consists of 55 terms and is intended to facilitate the exchange of and the search for bibliographic data on the Internet. DwC and ABCDEFG include several of these terms and can thus be considered spin-offs of the Dublin Core standard. The Dublin Core standard consists of a list of terms that can be imagined as fields in a database table. For each term, a Label (fieldname), a Definition (strict definition of the field content) and a Comment (extended explanation of the field contents, its format etc.) as well as further attributes are provided (see figure 4.3.1.a for an example). Dublin Core uses Extended Markup Language schemas (XML), which are machine- and human-readable, and has a very low degree of order. Furthermore, there is no prescribed order for presenting or using these elements. The intention was to exchange 'understandable' data (not unique or unequivocal data) and almost no restrictions exist concerning data formats or contents.

Term Name: contributor	
URI	http://purl.org/dc/elements/1.1/contributor
Label	Contributor
Definition	An entity responsible for making contributions to the resource.
Comment	Examples of a Contributor include a person, an organisation, or a service. Typically, the name of a Contributor should be used to indicate the entity.
Type of Term	Property
Version	http://dublincore.org/usage/terms/history/#contributor-006
Note	A second property with the same name as this property has been declared in the dcterms: namespace (http://purl.org/dc/terms/). See the Introduction to the document 'DCMI Metadata Terms' (http://dublincore.org/specifications/dublin-core/dcmi-terms/) for an explanation.

Figure 4.3.1.a: Example of the term 'contributor' as defined by the Dublin Core metadata standard

4.3.2 Darwin Core

The Darwin Core standard is developed and maintained by the Biodiversity Information Standards association (TDWG) and similar to the Dublin Core standard, provides an XML metadata schema in the form of a list of terms (see figure 4.3.2.a) that are grouped into classes. The majority of these terms can be considered as columns in a simple spreadsheet or fields in a database and Simple Darwin Core (a predefined subset of terms), can essentially be described as a 'flat file', in other words, a file containing data that can be shown in a single table (Wieczorek et al. 2012). However, Darwin Core is under constant development and has been extended in recent years. Although not explicitly mentioned, the higher degree of organisation into classes resembles the ordering or hierarchical structure typical for databases. At the present moment, approximately 170 terms are grouped into 15 Darwin Core classes, which represent different themes. In contrast to Dublin Core, Darwin Core recommends the use of strict formats or vocabularies. The complete Darwin Core standard is also available as a Resource Description Framework (RDF) document.

scientificName (Property)	
Identifier	http://rs.tdwg.org/dwc/terms/scientificName
Name	ScientificName
Definition	The full scientific name, with authorship and date information, if known. When forming part of an Identification, this should be the name in lowest level taxonomic rank that can be determined. This term should not contain identification qualifications, which should instead be supplied in the IdentificationQualifier term.
Comments	
Examples	Coleoptera (order). Vespertilionidae (family). Manis (genus). Ctenomys sociabilis (genus + specificEpithet). Ambystoma tigrinum diaboli (genus + specificEpithet + infraspecificEpithet). Roptrocerus typographi (Györfi, 1952) (genus + specificEpithet + scientificNameAuthorship), Quercus agrifolia var. oxyadenia (Torr.) J.T. Howell (genus + specificEpithet + taxonRank + infraspecificEpithet + scientificNameAuthorship).

Figure 4.3.2.a: Example of the term 'scientificName' as defined by Darwin Core

The Darwin Core standard was primarily built to facilitate the exchange of biodiversity data and is often used in this context today. The Global Biodiversity Information Facility GBIF, for example, supports it as its main standard. The exchange of data from natural history collections, however, was never the primary objective for use. The Darwin Core standard only represents a rather restricted list of terms, which do not cover all realms of natural history collections. Geodiversity data in particular (e.g. all collection data from mineralogy, petrology, etc.) are insufficiently covered by this standard.

To identify the most important or mandatory terms of Darwin Core for natural history data, SwissCollNet conducted a survey among curators and scientific employees from the Natural History Museums and Botanical Gardens of Geneva, Basel and Bern in 2020. Around 90% of all terms were marked as important or mandatory by at least one or more participants, even when considering only daily database work. Selecting a minimum list of important terms, as was initially planned, was thus not feasible. Obviously, the Darwin Core standard represents a significant number of key terms also within the context of natural history collections.

4.3.3 ABCD Schema (Access to Biological Collection Data)

The Access to Biological Collection Data schema (ABCD) is developed and maintained by the Access to Biological Collections Data task group of TDWG. Like Dublin Core and Darwin Core, ABCD represents an XML metadata schema in the form of a list of terms (Properties), which are grouped into classes. Properties are divided into Object- and Datatype Properties (see figures 4.3.3.b and 4.3.3.c). With a set of 780 data elements plus 240 attributes, the ABCD schema is much richer, more comprehensive and structured than the Darwin Core standard but it is also more complex. For example, the ABCD schema can store one-to-many relationships, which is only possible through extensions in the Darwin Core standard.

Figure 4.3.3.a: Bird skins of the ZMZ in Zürich (photo Martina Schenkel)

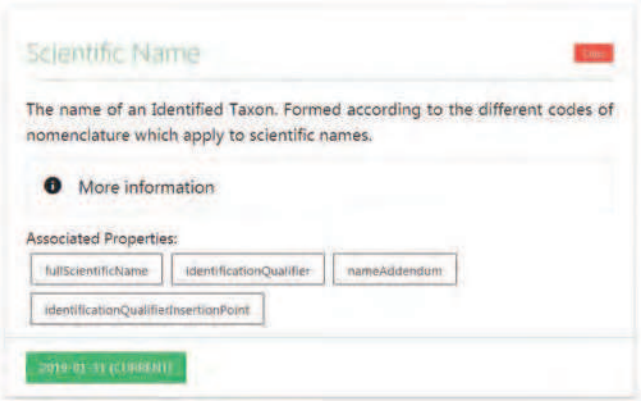

Figure 4.3.3.b: Short information example of the Class 'Scientific Name' with its associated elements (or Properties). A detailed explanation appears when clicking on the 'More information'' field

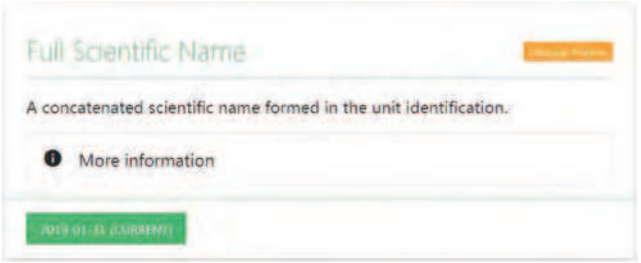

Figure 4.3.3.c: Short information example of the Datatype Property 'Full Scientific Name', a Property of the Class 'Scientific Name' (see figure 4.3.e)

The ABCD schema was designed for access and exchange of biodiversity data using databases located mainly in natural history museums. In its extended form ABCDEFG (Access to Biological Collection Databases Extended For Geosciences), it is intended to be a standard for all divisions of a natural history collection. GeoCASe develops and offers the EFG extension, which is an XML-Schema developed for use with digitised palaeontological, mineralogical and geological collection data (Petersen et al. 2018). The complete list of 840 additional concepts (Terms) of EFG can be found on the TDWG website. Two other main extensions of the ABCD schema are GGBN (Global Genome Biodiversity Network) and HISPID (Herbarium Information Standards and Protocols for Interchange of Data).

Higher structural degrees and additional restrictions make the ABCD schema an important standard for an automated and easy exchange of data. Furthermore, an ontology was established in version 3.0 for the first time. Finally, the ABCD schema is now also expressed as a Resource Description Framework (RDF) document, which is no longer human readable but adapted to an exchange of information between machines. The ABCDEFG schema is currently the main exchange standard in use by the BioCASe and GeoCASe networks. The schemas are also supported by GBIF.

Recommendations

- → use a collection Management System that supports the Darwin Core standard and ABCDEFG schema
- → use Darwin Core if an exchange of information exclusively concerns biodiversity data. For the exchange of data related to natural history collections, use ABCDEFG
- → if no standard has been implemented, examine the current data structure and develop a mapping with the Darwin Core standard or ABCD schema. An incorporation of all terms is not necessary. Adopting a subset of the terms matching the requirements of the particular collection is adequate and best practice

Suppliers

- the Biodiversity Information Standards association (TDWG) offers the Darwin Core standard: https://dwc.tdwg.org
- TDWG offers the ABCD schema: https://abcd.tdwg.org
- the EFG extension for the ABCD schema can be downloaded here: https://terms.tdwg.org/wiki/ABCD_EFG
- the BioCASe Provider Software can be used to establish a mapping between local databases and the BioCASe repository: www.biocase.org/products/provider_software
- a minimal set of required or recommended terms for 'metadata, occurrence and event' is defined by GBIF: https://github.com/gbif/ipt/wiki/howToPublish
- an (older) mapping between Darwin Core and ABCD can be found on https://archive.bgbm.org/TDWG/CODATA/Schema/Mappings/DwCAndExtensions.htm

Further reading

- for a detailed description of the relationship between the Darwin Core standard and the ABCD schema, see Steve Baskauf's blogpost: https://baskauf.blogspot.com/2019/06/comparing-abcd-model-to-darwin-core.html
- see Darwin Core Hour series: A series about Data Standards (not just restricted to Darwin Core): https://github.com/tdwg/dwc-qa/wiki/Webinars#chapter15

4.4 Data vocabularies

Controlled vocabularies facilitate the interpretation, searchability, exchange and visualisation of natural history data. They offer a backbone for organising, cataloguing and retrieving information from collections and allow for consistency in the assignment of identical terms to similar content. Through the use of controlled vocabularies, a common understanding across scientific domains is facilitated, as may be important in natural history collections. 'Controlled' in this context refers to the fact that the group of terms is recorded and defined so that each term is unique and non-overlapping. For researchers, this greatly facilitates accessing datasets from different sources.

Use of vocabularies

Controlled vocabularies consist of terms from natural language and are used to define, describe and categorise objects. For example, in natural history collections, drop-down lists can be used to provide expressions that cataloguers or researchers only have in their passive vocabulary. In this sense, vocabularies can guide data entry. It is becoming best practice for institutions to link the terms in their collection management systems (e.g. instances of species or for people) to external resources through unique identifiers (Dillen et al. 2019). This will simplify the harmonisation of data with other collection management systems that use the same identifiers.

Controlled vocabularies can be classified into categories such as lists of terms, taxonomies, thesauri and ontologies (Harpring 2010). Lists of terms are controlled vocabularies without any structure or hierarchy. Each term is unique and non-overlapping in meaning with other terms. For better usability, the terms should be arranged alphabetically or in another logical order. Taxonomies are more complex, as the terms of controlled vocabularies are organised into a (poly-)hierarchical structure. Each term is in one or more parent-child relationships to other terms. In the present context, the term 'taxonomy' is used exclusively to describe a structured vocabulary and should not be confused with the science of naming, describing and classifying biological organisms. Thesauri, finally, differ from taxonomies by allowing more complex structures, such as associative relationships (see figure 4.4.b). The term ontology is also frequently used to describe vocabularies of all sorts. In a strict sense, it is a controlled vocabulary expressed in a language specific to the particular ontology. While these different terms are useful in computer linguistics and information sciences, their utility in the natural sciences is debatable.

Figure 4.4.a: Minerals in the BNM in Chur (photo Stephan Liersch)

Editing and control of vocabularies

Controlled vocabularies are supervised by authorities, which eliminate ambiguities, control for synonyms, test and validate the terms, and establish relationships among terms where appropriate (NISO 2005). Most authorities are nowadays international organisations such as the Species 2000 Secretariat at Naturalis Biodiversity Center in Leiden, Netherlands, which publishes the Catalogue of Life database. If no national or international vocabularies exist (e.g. taxonomy for metamorphic rocks), the establishment of a centralised

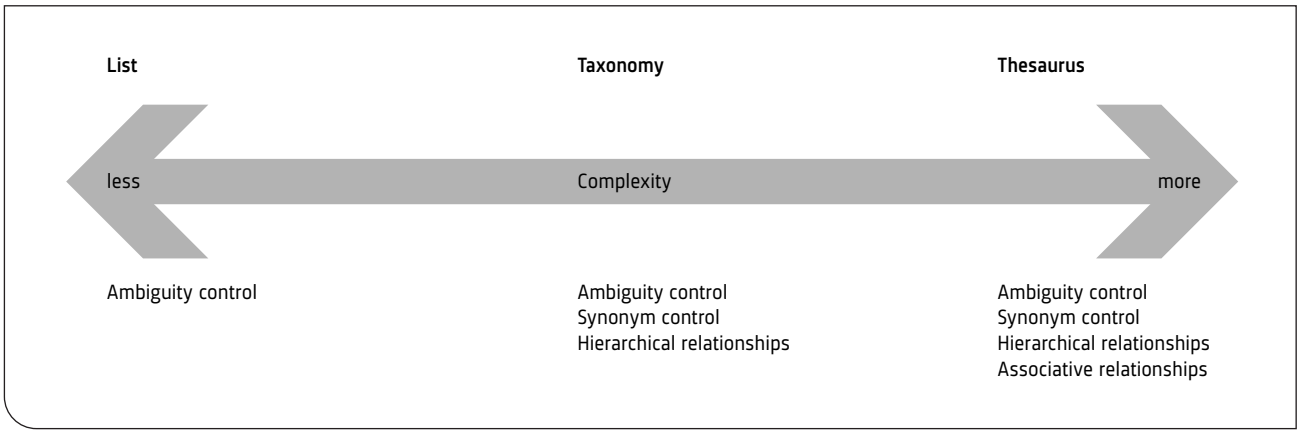

Figure 4.4.b: Increasing structural complexity among controlled vocabularies (adapted from NISO (2005))

national administration coordinating the development of controlled vocabularies might be advisable.

Along with controlled vocabularies, collaboratively edited sources of information such as Wikidata have proven to be viable alternatives. Especially in intensively investigated areas with lively expert communities, open collaboration may be faster, more efficient and more precise than central authorities. No matter which authorities are involved, a common understanding concerning a defined group of terms is central to effective data exchange and comparing content when working with collections.

Recommendations

→ use open, externally controlled vocabularies
→ use unique identifiers to link terms of vocabularies to external recognised resources

Examples

- the Open Biological and Biomedical Ontology (OBO) Foundry develops a family of interoperable ontologies, amongst others the Biological Collections Ontology
- the registered cooperative digiCULT develops 'xTree', which is a web-based tool for the collaborative management of controlled vocabularies. With xTree, vocabularies can be maintained and developed across institutions. The basis for interoperability is the current ISO 25964-1 standard. Archäologie und Museum Baselland are currently preparing the utilisation of xTree
- GBIF Backbone Taxonomy provides unique identifiers for taxonomic names, including identifiers for so-called operational taxonomic units (OTUs) drawn from the barcoding resources iBOL and UNITE
- the Integrated Authority File (German: Gemeinsame Normdatei GND) was developed for the documentation in libraries and provides controlled vocabularies for the organisation of corporate bodies, personal names and subject headings

Further reading

- for an introduction to controlled vocabularies, see Harpring (2010)
- for guidelines for the constructions and management of controlled vocabularies, see NISO (2005)

4.4.1 Earth Sciences

The origin of minerals and rocks is complex and, to date, an authoritative index describing geodiversity in a uniform and comprehensive way is lacking. Instead, individual classification schemes exist for different classes of minerals and rocks, which are based, for example, on crystallography, geochemistry or sedimentary features. These classifications can be translated into vocabularies, yet do not form a common taxonomy by any means. Not only are there different vocabularies for each discipline of the Earth Sciences but even individual museums and collections maintain their own indices. In the following sections, a compilation of the most often used and cited classification resources, which range from simple lists or diagrams to detailed books, illustrate this complex situation.

Taxonomies in the Earth Sciences may represent controlled and hierarchically ordered vocabularies but may also include systems of lesser complexity, such as glossaries. Separate taxonomies exist for minerals (based on crystal structure and chemistry), rocks (based on rock composition in a broader sense) and palaeontology (mainly based on fossil records). Meteorites could be treated in

a separate taxonomy but may also be included in rock taxonomy (actually meteorites are 'celestial' rocks).

Figure 4.4.1.a: Minerals from the NMSO in Solothurn (photo Thomas Briner)

Mineralogy (minerals)

The International Mineralogical Association (IMA) approves mineral names and publishes the authoritative list 'IMA List of Minerals' (see Schertl et al. 2018 for the IMA nomenclature). This list, however, lacks taxonomical arrangement and information on synonyms or names of unapproved minerals. For mineralogical taxonomies, the Nickel-Strunz Classification (9th and 10th edition) should be consulted (Strunz and Nickel 2001). Internet resources such as the Mindat database may assist in resolving issues with synonyms.

Petrology (rocks)

Instead of a standard classification for all 'rocks', separate recommended standard classifications exist for igneous, metamorphic and sedimentary rocks, as well as for meteorites. The International Union of Geological Sciences (IUGS) published a nomenclature for igneous rocks (Le Maitre et al. 2002). Although not hierarchically ordered, it should be considered the standard and builds on the classification schema by Streckeisen (1976) and proposes additional nomenclature for volcanic rocks. The various redundant local names (geological equivalents of biological synonyms) should no longer be used. Similarly, IUGS published an extended but unstructured vocabulary on metamorphic rocks, which should be considered the standard nomenclature and which discusses the use and validity of terms, as well as obsolete names (Fettes and Desmon 2007).

For sedimentary rocks, several nomenclatures exist rather than a single standard. For clastic rocks, ISO 14688 is used for granulometry, Stow (2008) for conglomerates and pelites and Pettijohn et al. (1987) for sandstones. Carbonate rocks are classified according to composition (Folk 1962, 1974) or sedimentation structures (Dunham 1962, Embry and Klovan 1971, Wright 1992). Siliceous sediments, phosphate sediments, coals and evaporates are discussed in Stow (2008). The classification of meteorites is still under development but the most often employed schema is published in Weisberg et al. (2006).

Figure 4.4.1.b: Palaeontological samples at the PIM in Zürich (photo Torsten Scheyer)

Palaeontology

The nomenclature of fossils is regulated by different international codes of biological organisms, such as those used for plants or animals, and comprehensive indices are provided by the Paleobiology Database and the Catalogue of Life initiative (see section 4.4.2). The following online and printed resources are also relevant in palaeontology. The University of Kansas released the Treatise on Invertebrate Palaeontology and Benton (2014) and Carroll (1997) published overviews on vertebrate fossils. For plant fossils, relevant information is offered by the International Organisation of Palaeobotany and authoritative vocabularies by the Plant Fossil Names Registry and The International Fossil Plant Names Index (both using unique persistent identifiers).

Further vocabularies

Additional relevant vocabularies for chronostratigraphy and biostratigraphy follow the recommendations of the International Commission on Stratigraphy (Cohen et al. 2013). In lithostratigraphy and tectonostratigraphy, governments publish the most up to date or homogenised data through their geoportals or websites (see Examples).

Recommendations

→ treat discredited local taxonomic names as synonyms
→ use only the newest and official nomenclature and move outdated expressions to separate fields
→ use resources offering unique persistent identifiers where available

Example

- the Geological Survey of Switzerland (Landesgeologie) is harmonising all lithostratigraphic units of Switzerland. The Lithostratigraphic Lexicon of Switzerland (https://www.strati.ch/en) contains the most up to date information and will represent the authoritative vocabulary in the future. Upon completion, the use of this vocabulary should be considered mandatory for Switzerland. LithoLex (Lithostratigraphisches Lexikon Deutschland) is the corresponding service in Germany. Similar services exist for many countries in Europe

Suppliers

- IMA list of minerals: http://cnmnc.main.jp
- Mindat database of minerals, rocks, and meteorites: www.mindat.org
- Plant Fossil Names Registry: www.plantfossilnames.org
- the International Fossil Plant Names Index: http://fossilplants.info
- International Commission on Stratigraphy: https://stratigraphy.org
- the Paleobiology Database: https://paleobiodb.org

4.4.2 Biological taxa

Taxonomists have been busy with naming, defining and classifying groups of biological organisms for centuries. They created true masterpieces of controlled vocabularies and established international standards and commissions on nomenclature long before data interoperability was an issue. In recent decades, the advent of the Internet and the coalescence of scientific landscapes worldwide have accelerated the rate of information exchange and significantly improved the consistency of nomenclatures. In this respect, one of the main goals of current international taxonomic initiatives is the establishment of globally accepted and well curated nomenclatural databases.

The formal naming of biological organisms is administered by several international commissions. The International Commission on Zoological Nomenclature (ICZN) publishes the International Code of Zoological Nomenclature, which defines the rules for the formal naming of all animals. Located in London until 2014, the Commission is now supported by a small secretariat based at the National University of Singapore.

The remaining naturally occurring eukaryotes are covered by the International Code of Nomenclature for algae, fungi and plants (ICN – Turland et al. 2018), which replaced the former International Code of Botanical Nomenclature (ICBN). Supported by the International Association for Plant Taxonomy (IAPT), with its secretariat in Bratislava, this code can be changed every 6 years by an International Botanical Congress only, based on proposals made by the community and published in TAXON. As a specialty, the International Code of Nomenclature in Cultivated Plants regulates the naming of plants that have originated due to human activity. And finally, the International Code of Nomenclature of Prokaryotes (ICNP) handles the formal naming of Bacteria and Archaea and the International Committee on Taxonomy of Viruses (ICTV) authorises and organises the taxonomic classification and nomenclatures for viruses.

Online databases

A multitude of geographically or taxonomically specialised online databases have started to provide indices of known species in recent years. Although comprehensive in their fields, these indices were of limited use for more generalised institutions and initiatives, and a global solution encompassing all domains and geographic areas was increasingly necessary. In 2015, therefore, several biodiversity information organisations took the first step toward building a single shared authoritative taxonomic backbone (Bánki et al. 2018). The Catalogue of Life (CoL) initiative was selected by Biodiversity Heritage Library (BHL), Barcode of Life Data systems (BoLD), Encyclopedia of Life (EoL) and Global Biodiversity Information Facility (GBIF) to deliver a global, consistent and normalised index of all species concepts and names. All of these organisations now use the Catalogue of Life as their principal taxonomic index.

To date, the Catalogue of Life features over 1.8 million living and around 40,000 extinct species, corresponding to 80% of the world's known species. It is currently the most comprehensive and authoritative index of known species of fungi, plants, animals, micro-organisms and viruses and compiles information from around 170 taxonomic databases from all around the world, thus including contributions from more than 4000 taxonomic specialists from throughout the world (Ruggiero et al. 2015). Some taxonomic groups are globally complete, others are at intermediate stages. Checklists of the catalogue are published online annually. These are versioned snapshots of the entire Catalogue of Life index and can be cited at any time

Figure 4.4.2.a: Some owls of the NSFL in Triesen (photo Holger Frick)

in the future. In addition, updates without versioning are published online on a monthly basis.

The Catalogue of Life is maintained by Species 2000 and ITIS, the Integrated Taxonomic Information System. The Species 2000 secretariat is at Naturalis Biodiversity Center in Leiden, Netherlands, and the ITIS content staff are housed at the Smithsonian National Museum of Natural History in the United States. Investments in the Catalogue of Life initiative have been primarily made by the Dutch Government and the European Commission.

Recommendations

- → use the Catalogue of Life index as a backbone and add, if necessary, scientific names exclusively found in other datasets
- → in historic collections, specify the taxonomic standard or expert that they refer to (e.g. Reptiles according to Müller, 1898)
- → record historic identifications of names, e.g. synonyms, single taxon split into several taxa, historic identifications. Many collection management systems offer tools to document historic determinations and assist in managing synonyms

Examples

- for a specialised taxonomic vocabulary, see the World Spider Catalog published by the Naturhistorisches Museum Bern: https://wsc.nmbe.ch
- in botany, two main references are used for nomenclatural purposes – International Plants Names Index (www.ipni.org) and Tropicos (https://www.tropicos.org/home) – as well as for the registration of botanical authors and collectors
- for the latest accepted taxonomic system of the Mollusca, see www.molluscabase.org

Further reading

- for details on the Catalogue of Life index, see Ruggiero et al. (2015)

4.4.3 Persons

Natural history collections are creations of both nature and human activity. With regard to the latter, they should be considered as extraordinary cultural achievements. Humans collected the specimens, invented sophisticated methods of preparation and intricate organisation systems and generated a universe of publications and knowledge about collection objects over the centuries. The attribution of specimens to a collector contextualises these specimens and opens up a broad range of new questions and possibilities for use. Travel routes of collectors, for instance, can be plotted from their specimen labels and may provide important insights into historical figures for

Figure 4.4.3.a: Researcher examining herbarium specimens in the CJBG in Geneva (photo CJBG)

history of science students (e.g. Pierce et al. 2016). Data on persons related to natural history collections are therefore essential for comprehensive data curation as well as scientific studies. As a result, various initiatives worldwide aim to unambiguously identify these people.

VIAF – Authority files of the library domain

Originating from library initiatives, several international authority files offer well-curated, high-quality data. Most prominently, the Virtual International Authority File (VIAF) offers a system for the identification of a wide range of persons, corporate bodies and historical entities. Hosted by the Online Computer Library Center (OCLC) in the United States, it is an international service for the library domain, aggregating authority file data from over 40 national libraries and additional institutions worldwide. Contributing partners are for instance the Schweizerische Nationalbibliothek, the Deutsche Nationalbibliothek, the Library of Congress and the Bibliothèque nationale de France. VIAF enables users to identify names (persons, subjects, institutions) while preserving regional preferences for language, script and spelling. For referencing, a VIAF data record is given its own standard data number as an identifier, which is a uniform resource identifier (URI) that can be used for linked data applications. Broader in scope than VIAF and including the VIAF identifiers is the International Standard Name Identifier (ISNI), which aims to generate persistent identifiers for persons across all fields of creative activity (Groom et al. 2019a).

VIAF and other international authority files score well in data reliability but have considerable limitations in the context of natural history collections. Since editing and contributing data is exclusively reserved for accredited libraries, collections face difficulties with registration. In this respect, collaboratively edited databases such as ORCID and Wikidata provide alternative solutions, as anybody can contribute and update information.

ORCID – Unique identifiers for living scientists

With more than seven million users, the Open Researcher and Contributor ID (ORCID) represents the most widely used system providing persistent digital identifiers for scientific authors. It was developed to connect scientists with their publications, manuscripts and grant submissions, thereby ensuring recognition of their work. In practice, persons interacting with research and natural history institutions such as collectors, donors of specimens, curators and data managers can register likewise. Registration can exclusively be done by the persons themselves (and not by a third party). Convincing every living person related to a collection to register at ORCID should henceforth become best practice.

Figure 4.4.3.b: Scientist examining insects at the NMBE in Bern (photo Lisa Schäublin)

Wikidata – Registry for deceased persons

Specimens of deceased persons without publication records are ubiquitous in all natural history collections. Such contributors frequently distinguish themselves by their prolific collecting, despite a lack of publications. Wikidata is a collaboratively edited source of information and is an appropriate solution for the registry of such persons, as anybody can create or modify entries (www.wikidata.org). Wikidata creates unique identifiers for persons and further entities, links to several other data platforms such as Wikipedia, VIAF and ORCID and provides data in both human- and machine-readable format. Special attention should be paid to information privacy. Although publishing names of researchers and collectors on specimen labels is common practice in natural history museums, biographical information of these persons should be considered sensitive data and must be restricted in some cases. It is advisable to clarify these issues prior to accepting a donation.

Recommendations

- → use persistent digital identifiers for all persons related to collections (for example, collectors, taxonomists)
- → use VIAF when possible
- → use ORCID to register living persons
- → use Wikidata to register deceased persons
- → clarify issues of personal data protection before acquiring collections

Example

- Wikispecies makes widely use of VIAF and ISNI identifiers for cross-linking: https://species.wikimedia.org/wiki/Oswald_Heer

Suppliers

- https://viaf.org provides persistent identifiers for living and dead people with a publication record

- www.isni.org provides persistent identifiers for persons across all fields of creative activity
- https://orcid.org provides persistent identifiers for living researchers
- www.wikidata.org provides persistent identifiers for all others

Further reading

- for cases using ORCID identifiers, see Thomas et al. (2015)
- for management of ambiguities in VIAF, see Hickey and Toves (2014)
- for an introduction to Wikidata, see Vrandečić and Krötzsch (2014)

4.4.4 Geography

Besides information on dates and collectors, geographic locations of specimens are among the most important label data. They can be used in a multitude of scientific and other settings thus their precision and clarity is of paramount importance. Location information should therefore be transcribed verbatim to facilitate subsequent verification of original label data. In a further step, locations must be described by controlled vocabularies and geographic coordinate systems. GeoNames is among the most popular gazetteers (i.e. geographical index) worldwide, offering over 25 million geographical names. It combines data from more than 380 data sources such as the Swiss Federal Office of Topography 'swisstopo', the German Bundesamt für Kartographie und Geodäsie and the French Institut national de l'information géographique et forestière. Each term in GeoNames features a unique persistent identifier, latitude and longitude, and versions of the name in various languages. Besides international gazetteers like GeoNames, a multitude of smaller, regional vocabularies exist such as the Historisches Ortsverzeichnis von Sachsen (Baudisch 2006), which offers historical place names from Saxony. For interoperability with other repositories and collection management systems, the availability and utilisation of unique persistent identifiers must be ensured.

Apart from indexing with controlled vocabularies, location data should be enriched with geographic coordinates to facilitate their use in mapping applications (e.g. via GBIF), georeferenced studies and analyses using Geographic Information Systems (GIS). In Switzerland, many collections still use the Swiss coordinate system (i.e. Swiss grid). As most Swiss collections not only hold Swiss specimens (Beer et al. 2019) but also specimens from a multitude of countries, it is advisable to use a coordinate system which is applicable to all objects of a collection. In this respect, the World Geodetic System (i.e. WGS84 in its latest version) is the global standard used by most collections, as well as many other institutions and commercial providers such as the Global Positioning System GPS. Finally, most locations describe an area rather than a single point in space. To account for this, locations can be described by a polygon, for example, or by a point with an error radius (Wieczorek et al. 2004).

Examples

- swissNAMES3D is the most comprehensive vocabulary of Swiss geographic names, offering more than 400,000 geo-referenced entries and unique identifiers for each entry. It is one of the datasource for GeoNames: https://shop.swisstopo.admin.ch/en/products/landscape/names3D
- the Getty Vocabulary Program produces and maintains a range of controlled vocabularies in the artistic field, inter alia the Getty Thesaurus of Geographic Names, which stands out because of its international coverage of historic place names (Fink 1999)

Supplier

- for GeoNames, see www.geonames.org

4.5 Collection Management System (CMS)

Natural history collections in institutions are in a state of constant change, given that incoming donations increase the size of holdings, collection objects are displayed in exhibitions, specimens are enriched with additional metadata (e.g. DNA sequence data) and collection units are rearranged due to taxonomic revisions. Collection management systems (CMS) are thus essential tools for administering a collection and making the best use of it. Collection management systems are software solutions developed for natural history and other collections that may hold information about the objects and their storage locations, the number of specimens per taxon, loan activities, or pest damage and prevention measures, as well as collection permit numbers and ABS compliance information. In an ideal case, a collection management system is comparable to the intelligence service of a collection, keeping track of all holdings and permanently updating records with any changes. Due to the dynamic nature of collections, however, and the wide range of potential information that may be included, any collection management system will always be incomplete and in need of continuous development.

Over recent decades, many natural history collections in Switzerland switched from paper-based catalogues and card systems to electronic lists and databases. Most started with simple spreadsheets and later changed to more sophisticated program-based management systems. As the inter-institutional exchange of data was less common and collection management systems were neither readily nor publicly available, data associated with specimens deposited in natural history collections were mostly managed using in-house solutions. These solutions offered maximum flexibility and were often perfectly tailored to the requirements of individual institutions.

With the advent of the Internet and international bio- and geodiversity databases, however, sharing data that was previously only internal has become one of the foremost priorities in collection strategies. Mass digitisation initiatives were started that not only served internal management purposes but also aimed to open collections to a wider public and exchange data in an international research context. As a result, interoperability with external repositories became one the most important requirements of collection management systems (Dillen et al. 2019).

Figure 4.5.a: Hummingbird skins at the NMBE in Bern (photo Lisa Schäublin)

Rather than adapting to the internal needs of individual institutions, a collection management system should nowadays comply with a multitude of international standards. As in-house solutions struggle to keep up with ever more complex specifications, third-party commercial or open-source management systems gain importance. Although there will never be a system that meets all requirements, the multitude of systems currently available can be expected to decrease over the next years in favour of fewer and more widespread solutions (Dillen et al. 2019).

4.5.1 Evaluation of collection management systems

Even if international repositories gain in importance, collection management systems at the institutional level will remain the focal points of data sovereignty. Despite the international harmonisation of requirements, individual institutions still need to select among a variety of very different management solutions and a number of factors should be taken into consideration.

Firstly, specialised small collections may choose a system optimised for their particular branch of natural history, like botany or palaeontology, whereas more generalist and larger museums may want an all-encompassing solution covering various branches and offering further modules, for example, to accommodate exhibitions. In any case, the efficient and effective discovery of all data related to a certain collection object should be ensured.

Secondly, a decisive selection criterion are the costs of acquisition and subsequent maintenance. They will depend on parameters such as hardware specifications (server infrastructure, workstations, backup solutions), licensing models, collection-specific customisations and distribution models (open source vs. proprietary solutions, commercial software vs. freeware), and often also ongoing user-support options.

Thirdly, versioning of data, i.e. the ability to reconstruct the status of a record at a given point in time in the past, should be addressed. Collection data and specimens are not static: taxonomic names change over time, images are added or removed, labels are interpreted differently and other information, like genetic sequence data, may be added. As more and more researchers use large datasets from various institutions to generate models for biodiversity and climate change research, reproducibility of results and correct interpretation of past studies are endangered by subsequent changes to datasets. Knowing the exact state, i.e. the version, of data at a given point in time is therefore pivotal to ensuring accuracy. To the authors knowledge, no collection management system offers full versioning functionality.

Lastly, the number of users and installations worldwide, seen as the popularity of a management system, will play a role in the choice of systems too, as widespread systems are more likely to inspire lively user communities and thus to thrive on the open market over time. Furthermore,

Figure 4.5.1.a: Moving a compactus with minerals in the NMSG in St. Gallen (photo Jean-Claude Jossen)

working on shared CMS platforms may promote the use of common vocabularies and facilitate the exchange of data.

In a recent survey, SwissCollNet gathered information on collection management systems installed at the larger natural history museums in Switzerland. They demonstrated that among the 30 participating institutions, more than half worked with a system built in-house. Over time, the increasing costs of maintenance and need for updating or program development may force these in-house solutions to transition to third-party management systems. Amongst others, possible reasons could be changes to the IT-personnel, missing functionalities or lack of interoperability with external repositories or with other in-house storage systems.

To choose an appropriate collection management system, a multistage evaluation process is advisable. Firstly, the requirements of all stakeholders must be analysed and priorities identified. Secondly, a shortlist of candidate solutions should be generated by a cursory examination of available collection management systems. In a third stage, an in-depth evaluation will reduce the number of systems to two or three candidates, which will then be involved in detailed negotiations. To facilitate the final evaluation, SwissCollNet summarised the requirement analyses of several leading Swiss natural history collections and generated a basic evaluation template, which can be found in Stöckli et al. (2021).

Recommendations

- → do not create your own collection management system
- → use only one collection management system per institution
- → perform a requirements analysis before choosing a collection management system
- → smaller institutions should consider cooperating with larger institutions, and larger institutions fostering smaller ones
- → versioning of data should be addressed urgently
- → data export from and import to the collection management system in a standardised manner must be prioritised
- → follow the FAIR data principles for maximum data interoperability and usability

Example

- in 2017, surveys on the use of collection management systems were done both by DiSSCo and Naturalis Biodiversity Center. Some of the questionnaires and results can be found in Dillen et al. (2019)

Suppliers

- SwissCollNet combined the requirement analyses of several Swiss Natural history collections and offers a condensed list (Stöckli et al. 2021)
- the Government of Canada provides resources to help select a suitable collection management system: www.canada.ca/en/heritage-information-network/services/collections-management-systems.html

Further reading

- for information on interoperability in collection management systems, see Dillen et al. (2019)
- for a discussion on selecting a collection management system, see Carpinone (2010)
- for a list of available collection management software solutions visit the Collections Trust: https://collectionstrust.org.uk/software

4.5.2 Examples of collection management systems used in Switzerland

There are several collection management systems on the market and some of these are in use in Switzerland. In the following sections, a selection of systems either already in use in Swiss institutions or in the process of being installed is presented.

The Specify Software Project

The Specify Software Project offers the collection management system Specify 6 as an open-source desktop application, and Specify 7 as a simplified version for web browsers. Developed at the University of Kansas in the United States, Specify 6 is widespread among collections in North America and also in use at many European institutions, for example at the Natural History Museum of Denmark and the Zoologisches Museum der Universität Zürich.

After a software evaluation process, the Muséum d'histoire naturelle de la Ville de Genève selected Specify 6 to replace their former collection management systems in 2019. The curators were drawn to the open-source philosophy, the comprehensiveness of the functions proposed and the reasonable price. Initially, Specify 6 was designed for managing biodiversity but not geological data. The Muséum d'histoire naturelle de la Ville de Genève therefore agreed to develop a new module for geological data

Figure 4.5.2.a: Bird skins of the MHNG in Geneva (photo Philippe Wagneur)

– probably in collaboration with the Naturhistorisches Museum Bern – once migration of the biodiversity data was completed. The module will be developed under the supervision of the Specify Collections Consortium and later integrated into the Specify 6 software environment. For the time being, the Specify Collections Consortium proposes to include geological data in the current version through customisation.

Specify 6 can be set up independently by an institution. Although tutorials and helpcast videos assist in the process, the setup is challenging and may take several months. Alternatively, institutions can become members of the consortium by paying an annual fee and then receiving support from the team of developers at the University of Kansas, both during and after the migration process.

The European research infrastructure DiSSCo aims to improve interoperability among collection management systems by supporting a new system called 'DINA'. DINA is not a collection management system in itself but rather an ecosystem of interoperable components. Examples of such components are a module for printing labels (including barcodes or QR-codes), a database for genetic sequence data and a module for research data. One of DINA's first interfaces for collection management systems will be developed for Specify 7.

Botalista

Botalista is an open source software developed by the Conservatoire et Jardin botaniques de la Ville de Genève to manage all core activities of botanical institutes, covering both living collections and herbarium collections, as well as associated scientific projects. Botalista is a web application and offers a DataShare Center that enables users to exchange a variety of data thesauri. The system consists of a set of modules covering different work processes, which can be installed according to the needs of the users. Based on a flexible subscription policy, collections without the necessary IT resources for deployment and maintenance may rely on the services of the Botalista Association. This new open source database will replace the current Système d'information botanique de Genève (SIBG) that was developed over 20 years ago to facilitate the management of the herbarium (specimen data entry and specimen loans) and living collections, as well as of its in-house scientific projects. The SIBG database is the current source of the on-line Collection Catalogue (Geneva Herbarium Cata-

logue), as well as other reference databases provided by the institution.

Figure 4.5.2.b: Herbarium box of the NMTG in Frauenfeld (photo Eliane Huber)

Diversity Workbench

Diversity Workbench (DWB) is a modular collection management system for bio- and geodiversity data. It is developed and maintained by the Staatliche Naturwissenschaftliche Sammlungen Bayerns, Universität Bayreuth, and Museum für Naturkunde Berlin. Diversity Workbench is one of the two platforms recommended by the German Federation for Biological Data for data producers in biodiversity research projects. The code is free, well-documented and can be used by third parties.

Many components and functionalities have been added since development started in 2003, making Diversity Workbench one of the most comprehensive collection management systems currently in use. It is highly adaptable according to the needs of a project or a single user. All leading data exchange standards (e.g. Darwin Core) are implemented, as well as automated export functionalities for compatibility with GBIF. The single modules of the system can be used separately or in combination as a complete workbench.

BioOffice

For over 20 years, the collection management system BioOffice has been used by a large community of smaller and larger Austrian, German and Swiss museums and nature related institutions. The completely new version BioOffice 3 is developed by the Tiroler Landesmuseum and the Zürich based company myself AG in collaboration with the Naturhistorisches Museum Basel. BioOffice 3, currently in test phase, will offer modules for zoological, botanical, geological and paleontological collections.

The modular system incorporates taxonomy, contacts, locations, collections, literature, excursions, projects and object management. Further sub-modules include GIS mapping, identification history (the next release will include preparation history too), taxonomic synonymies, a report generator (Jasper Reports), a loan management function, a complex query manager and storage of multimedia data locally or on the web. Different options are available for the import and export of data; connectivity to national and international databases like GBIF are possible. BioOffice runs on most operating systems including Windows, MacOS and Linux.

It allows user friendly and easy adaption of the GUI (graphical user interface) that may be stored per user or by user groups. All lookup tables are customisable and can be created by the administrator for each collection individually.

easyDB

ETH-Library is currently implementing a new database with the commercial provider Programmfabrik GmbH for several collections belonging to the ETH Zürich (herbarium, geology, entomology, xylotheque and fungarium). ETH-Library will be hosting the web application and provide support for the collections. Although the core system of easyDB must be licensed, it is possible to develop plugins on an open source basis. There is already a growing community of university collections in Germany that build on this system (i.e. naniweb). Furthermore, the ETH-Library plans to offer digital storage space and services for external natural history institutions that have their objects digitised but lack the resources to build and maintain their own infrastructure (CMS-as-a-service). The implementation, running under the name NAHIMA, will offer modules for registration and cataloguing of specimens, determinations, collecting and georeferencing, management of location names, provenance, loans, pub-

Figure 4.5.2.c: Palaeontological collection at the NMB in Basel (photo Basil Thüring)

lications, projects, excursions and digital asset management. The vocabulary control offers modules for taxonomy, people and institutions and a gazetteer. The authority files of GND and geonames are integrated. The system provides an OAI-PMH interface and a Rest-API, supporting the export of data in the formats ABCD, ABCDEFG and Darwin Core.

Examples

- Specify is currently used by Muséum d'histoire naturelle de la Ville de Genève and Zoologisches Museum der Universität Zürich and under evaluation by several other Swiss museums
- Botalista, developed by the Conservatoire et Jardin botaniques de la Ville de Genève is currently also used by the Botanischer Garten der Universität Bern and the Jardin botanique de Neuchâtel
- Diversity Workbench is currently under evaluation by the Naturhistorisches Museum Bern
- BioOffice is currently used by Naturhistorisches Museum Basel, Bündner Naturmuseum in Chur, Natur-Museum Luzern, Naturmuseum Solothurn, Botanisches Museum der Universität Zürich, and Naturmuseum Winterthur
- easyDB is currently used by the ETH Bibliothek, the Entomologische Sammlung der ETH Zürich, the Erdwissenschaftliche Sammlungen der ETH Zürich, the Forstwissenschaftliche Sammlung und Xylothek der ETH Zürich, and the Vereinigte Herbarien der Universität und ETH Zürich

Suppliers

- for the Specify Software Project, see www.sustain.specifysoftware.org/products/specify-6
- for Botalista, see https://botalista.community
- for Diversity Workbench, see https://diversityworkbench.net/Portal/Diversity_Workbench
- for Bioffice, see https://biooffice.org/features_de.php
- for easyDB, see www.programmfabrik.de

4.6 Data storage and preservation

Most medium-sized and large Swiss natural history collections preserve and store their data on in-house server infrastructures and organise their data in collection management systems (CMS). On a national level, however, Switzerland still lacks a centralised data preservation and storage facility, despite a great number of potential advantages. First, data exchange with international research infrastructures such as DiSSCo or iDigBio would be greatly facilitated as data would be standardised on the national level prior to international exchange. Acting en bloc would allow Swiss natural history collections to advance national interests, which may also exist at the level of data storage and exchange, in an international context. Furthermore, by centralising data from all natural history collections in one location, physically divided nominal collections would be virtually unified again and data from different sources could be easily linked for scientific purposes, for instance when investigating plant-pollinator interactions, or host-pathogen relationships.

Secondly, Switzerland features a multitude of small, regional natural history collections that lack the resources to implement their own CMS. A national data storage infrastructure could extend its service range and offer data management facilities as a service, known in jargon as 'CMS-as-a-service' (CMSaaS). To do so, any given CMS meeting the relevant technical requirements could be installed on the national server. Individual collections would then receive an account and could curate their data using a CMS hosted by the national server, thereby by-passing the need to maintain their own data storage infrastructure. For larger collections, which tend to rely on their own storage systems in the first place, a national repository would offer a convenient backup solution for their data.

And lastly, joint online aggregation and accessibility to all Swiss natural history collections would not only be a first point of contact for many researchers but would also be useful for public outreach in various forms, including as a virtual natural history collection.

Figure 4.6: Birds from the MHNG in Geneva (photo Philippe Wagneur)

4.6.1 Building a national data repository

Considering how much server capacities have increased over recent years, the amount of data originating from natural history collections remains relatively small and their storage costs marginal. In 2020, external storage providers charge a few hundred Swiss francs per terabyte per year, including the backup of data on geographically separated server infrastructures. In total, Swiss natural history collections store around 60 million objects. If 20% of these objects were digitised over the next years by taking one ten-megabyte image per object, annual storage costs would amount to around CHF 50,000. More critical than storage, however, is data transfer speed across the network of collections, repositories and users, as inefficient connections increase response times and generally slow down processes. Likewise, a recent study by Agosti et al. (2019) identified transfer speed as one of the most critical parameters in the management of data distributed throughout a network. In addition, the number of read/write accesses can drive costs significantly.

Apart from cost, other parameters should be taken into account when setting up data storage infrastructure. Depending on the nature of the data and data protection regulations, storage infrastructures may have to reside in Switzerland and not abroad, or at least, not in certain countries. In case of personal data of collectors, for instance, the observation of data residency laws and the European General Data Protection Regulation (GDPR) should be consulted. Although quite unlikely, data repositories can be damaged by fires, earthquakes or other disasters. To prevent data loss in such cases, data backup in geographically distinct places is recommended. Lastly, the implementation, operation and maintenance of the server infrastructure require careful organisation and the infrastructure provider should be selected with due diligence.

Recommendation

→ consider the development of a Swiss storage infrastructure for natural history data, including a requirements analysis on a national level

Example

- as a provider of both very flexible server solutions and a high-speed network throughout Switzerland, SWITCH offers customisable storage infrastructure on a national level. SWITCH is a Swiss non-profit foundation responsible for the networks among Swiss universities and research facilities. It also manages the .ch country-code domain. Data are stored in two redundant databases in Switzerland (at Toni Areal in Zürich and Geopolis UNIL in Lausanne)

4.6.2 International data repositories

A data repository is a central place where aggregations of data can be stored in an organised and accessible way. Amongst international open-access research repositories, some serve a general purpose and accept all kinds of data from a range of scientific domains, while others focus on narrow thematic fields and on particular content types. The Registry of Research Data Repositories lists more than 2500 research repositories worldwide, most of which are tailored to a very specific research and user community. In the following, a few international research repositories relevant for natural history collections will be presented.

Generic repositories

Zenodo is a non-profit organisation operated by CERN, offering general-purpose open-access repositories with a ten-year storage guarantee. Zenodo can store metadata, reports, and other documents, as well as corresponding high-volume datasets, such as images or audio records. By generating a persistent digital object identifier (DOI) for each submission, stored items are easily citable.

Thematic repositories

GeoCASe provides an open-access data portal for geosciences collection data (Petersen et al. 2019). It uses the ABCDEFG scheme as the standard for data exchange. With regard to biodiversity collections, GBIF aggregates and offers access to data about all types of life on Earth. GBIF coordinates its activities through its secretariat in Copenhagen, Denmark, and works through its network of nodes in the participant countries.

GBIF was initiated by the Organisation for Economic Co-operation and Development (OECD) as an open-access infrastructure for worldwide biodiversity data and is funded by the participant countries. The network has a decentralised organisation with national nodes. The Swiss Node is the coordination organ designated by the Federal Office for the Environment responsible for implementing the GBIF Memorandum of Understanding. It has at its disposal an IT architecture provided by the IT Services of the University of Neuchâtel (SITEL) and is mandated to register, unify and coordinate the sharing of occurrence data from national data centres, museums and research institutions, with metadata on institutions and data resources as a prerequisite. The national coordinating organ ensures the coherence of Swiss data on the international portal and runs, together with partner institutions, a digitisation programme related to Swiss national

Figure 4.6.2.a: Hard rocks of the NML in Luzern (photo Gerry Nitsch)

species conservation programmes. It is committed to the development of common approaches for the management of sensitive occurrence data, especially with regard to the inter-governmental exchange of biodiversity data. Swiss occurrence records that have been validated by infospecies.ch, unified by GBIF's Swiss Node, are served to the Datacentre Nature and Landscape of the Federal Institute for Forest, Snow and Landscape Research (WSL) for direct access by agencies in charge of species and habitat conservation (cantonal, federal, administration of protected areas). Key activities in the work programme of the Swiss Node are the registration of national checklists, the linkage of genetic voucher information with the species information systems of the national data centres as well as a strengthening of trans-border cooperation.

Suppliers

- Registry of Research Data Repositories: www.re3data.org
- the Global Biodiversity Information Facility (GBIF): www.gbif.org
- the Geoscientific Collection Access Service (GeoCASe): www.geocase.eu

Further reading

- for a review of international research infrastructures, supporting collections digitisation, see Smith and Goodson (2020)

4.7 Metadata levels

Researchers, decision makers in administration, collection managers and other stakeholders need information on collection holdings for research purposes as well as for fact-based decision making. For them, mass digitisation has provided metadata in unprecedented dimensions.

Over recent years, label data from more than 185 million specimens found in natural history collections have been databased worldwide (GBIF Occurrence Store, accessed in May 2020). This number is impressive, yet in relation to the estimated three billion specimens deposited in global natural history collections, this can only be regarded as a first step (Wheeler et al. 2012). Digitising label data of individual specimens is slow and costly, and will take many decades before reaching any substantial percentages. To cope with the complexity and scale of this task in a timely manner, key figures, catalogues and summaries on larger collection units are therefore in demand. In the following sections, metadata on three different unit levels will be discussed: the collection unit as the most generalised entity, the storage unit representing an intermediate entity and the curatorial unit as the most detailed entity. As already explained in the introduction, the terms 'metadata' and 'data' will be used interchangeably throughout the text.

4.7.1 Collection unit level

What is a collection?

This question has been discussed extensively within museums, archives and libraries, especially in the context of Collection Level Descriptions (Dunsire 2011). Collection Level Descriptions consist of metadata describing collections or collection units as a whole, in contrast to descriptions of individual items. In practice, collections tend to be formed around categories such as taxonomic groups (e.g. molluscs, plants), geographic areas (e.g. Palearctic realm, the canton of Bern), persons (e.g. Oswald Heer, Charles Darwin), scientific or educational purposes (e.g. type collections, display collections), preparation types (e.g. wet collections, slides), historical events (e.g. donations, field excursions), curatorial state (e.g. damaged by pests, databased), physical location (e.g. in a new collection building, in a depository) and many more. Specimens may belong to several collections, within the institution, as collections may overlap in scope and content (Dunsire 2011). For example, a specimen may belong to the type collection and at the same time to the collection of a particular person. Furthermore, collections may have sub-collections or belong to super-collections.

A description at the collection unit level provides metadata pertaining to the entire unit. It should include information about the location of the collection and contact persons, species and other taxonomic groups represented, type specimens present, geographic areas covered, the availability of additional materials like images, field notebooks, sequence data and preparations, any associated datasets and databases, the history of specimens and how they arrived in the collection, contributing collectors and other relevant characteristics. These descriptions will help to assess the state and development of collections and to set priorities for research, curation and digitisation. They should facilitate cross-disciplinary, multi-level and multi-lingual access, as well as access for organisations, policy- and decision-makers, across disciplines, amongst resources with different types of content, and for audiences with varying levels of expertise and interests. Finally, they should also provide machine-readable information for other applications and for search engine optimisation (SEO).

Collection level descriptions help to map the complex landscape of research resources (Hobern et al. 2020). The first place to publish such information is generally via the website of the collection or institution in question. In the botanical community, Index Herbariorum is the directory of information on the world's herbaria, providing addresses, contacts, specialities, size, staff details and other

Figure 4.7.1.a: One of several herbaria at the MHNF in Fribourg (photo Michael Maillard)

Figure 4.7.1.b: Beaks in the NMB in Basel (photo Basil Thüring)

information. For other communities in natural history, no complete equivalents exist apart from regional or national infrastructures (e.g. iDigBio US Collections List). Within the community of natural history collections, a new discussion has therefore evolved around the idea of creating a world catalogue of collections and a digital research infrastructure in the natural sciences. Its goal is to develop a new vision for use cases, technology and governance for such a registry.

Join the dots

'Join the Dots' (JTD) is a cross-disciplinary collections assessment framework developed by the Natural History Museum in London and implemented in various institutions (Woodburn 2019). It is based on the Smithsonian Collections Standards and Profiling System (SCSPS, see next section), has an excellent and detailed user manual and is easy to apply. To better meet the needs of especially large, heterogeneous collections, several institutions have adjusted and refined the original system. While the descriptive part of the assessment framework is identical to that of the SCSPS system, the refinement concerns the numerical assessment of the collection. Woodburn (2019) gives a detailed summary in the user manual: 'Join the Dots quantifies collections and captures information across four assessment categories: Condition, Importance, Information, and Outreach. These categories are subdivided into criteria. There are 17 criteria in total.' The following is a brief explanation on the use of the framework and the opportunities it opens up.

Describing and scoring the collections according to 'Join the dots' takes time but the potential benefits far outweigh the costs. Knowledge about a collection is key to attracting researchers to work on the collections. Furthermore, information about the storage and curation status of the holdings is an important decision-making tool for stakeholders and funding agencies when assessing previous investments or planning future expenditures. And lastly, it raises the profile of a collection internally and externally, thus potentially raising awareness about collections that nobody feels responsible for anymore or which are in danger of damage or loss.

As a rule of thumb, a curator should work two to three days, at most, to score all the collections under his or her

responsibility. One unit should neither be to large (i.e. all specimens) nor to small (single specimen). The Natural History Museum in London defines a unit as 'a named group of objects that share the following core characteristics: a storage location, a curatorial unit type, a taxonomic level, a responsible curator and an object count/size estimate.' (Woodburn 2019).

Collections are assessed based on the personal judgment of the responsible curator and not on universal standards or criteria. For example, the 20,000 birds of a museum may be treated as one unit if curated by a single curator (irrespective of their organisation within the collection). Alternatively, they may be considered as separate units with regards to different taxa or to different types of objects (with various storage requirements) such as full mounts, nests, eggs, tissues and skins. Specimens from famous scientists or collectors like Charles Darwin may be kept separately from the main collection as separate units. Finally, the main collection may be split into a well-curated and fully integrated unit and a second unit that represents the hundreds of unsorted and unidentified specimens still awaiting integration. The possibilities are multiple and over time, units may be integrated into or separated from other units.

A standard set of collection attributes such as main collectors, taxa, locations and dates is described. All attributes should be evaluated, irrespective of the criteria used to define the collection unit. Attributes should be scored with regard to the condition of the collection (e.g. accessibility, storage, conservation), the importance and significance of the collection (e.g. mission, scope, usage), the information contained in the collection (e.g. documentation, identifications, digital records) and the utility for outreach (e.g. education, exhibitions).

Smithsonian Collections Standards and Profiling System (SCSPS)

The Smithsonian Collection Standards and Profiling System (SCSPS) is a management tool for a standardised assessment of collection holdings (McGinley 1989, 1993). Based on transparent grading, the system allows for identification of curatorial priorities and comparison between collections. Resulting expenditures in time, personnel and materials can be put together in a comprehensive and coherent way for decision-makers in charge. In addition, progress in curation within a collection can be measured after a baseline curation status has been established. And lastly, profiling assists in the timely identification of collections (i.e. SCSPS level = 1) that are in danger of irreparable damage or even permanent loss.

The system works by assigning a numerical code to the basic units used in collections. In summary, these levels are as follows:

- Level 1: Conservation problem
- Level 2: Unidentified unsorted material
- Level 3: Unidentified material, accessible
- Level 4: Material identified, but not incorporated into collection
- Level 5: Specimens identified but curation incomplete
- Level 6: Identified, integrated and adequately curated
- Level 7: Data capture: Species level inventory
- Level 8: Data capture: Specimen label data capture
- Level 9: Data capture: Research data capture

Recommendations

→ use Join the Dots templates to assess a collection

→ use the following workflow: First define collection units, second describe the attributes of each unit, and third score each unit based on criteria and rank definitions

Examples

- join the Dots is used at the Natural History Museum in London (Woodburn et al. 2019)
- SCSPS has been used at the Natur-Museum Luzern to assess its collections and also by the Naturhistorisches Museum Basel

Further reading

- for a practical guideline on Join the dots, see Woodburn (2019) including definition, description and scoring of collection units and for scoring tools
- for an original description of SCSPS system, see McGinley (1993)

4.7.2 Storage unit level

Storage units in natural history collections are units in or on which specimens are stored, such as shelves, drawers or boxes (see figure 4.7.2.a). Capturing metadata on the storage unit level is an efficient means of mapping the collection for research and curation purposes: the identification and location of specimens for loans is simplified, external scientists and the public are encouraged to engage with the collection by looking at images of drawers, for example and the remote determination of unsorted material is promoted. The type of data to be collected depends on the type of unit. It is best practice to record the most basic common factors of any entity, such as the taxon, location, date and collector and to save them as lists or metadata of associated photos. Given that most collections are in constant flux due to events including taxonomic revisions

and the integration of new material, it should be noted that images or unit level descriptions become obsolete as soon as specimens are moved from one unit to another.

Lists

In many collections, lists with information on collection units are already available. Especially in large collections, it is customary to first database the storage unit rather than the specimens. Here, specimens with a common denominator are usually housed together in standardised containers such as on herbarium sheets in a storage folder or box for a single plant species or insects of a particular genus in a drawer. The lists may also include information on the quality, size and location of storage units and on priorities with regard to evacuation plans.

Photos

Capturing photos and associated metadata of collection units is advisable if specimens are ordered horizontally such as in entomological or paleontological drawers (see figure 4.7.2.a). In contrast, units containing vertically stored samples like stacks of herbarium sheets, tiny specimens or those stored in jars and reflective or transparent objects like minerals or crystals are not suitable for imaging at the unit level. Depending on the imaging technology, large sections of the collection can be documented in high-resolution images in a short time. In most cases, however, little or no specimen data are accessible, as labels are covered by the specimen or other overlying labels.

The images will encourage researchers to work on the specimens and allow for better planning of visits as well as to the remote assessment of specimen quality. Furthermore, photos can document changes before and after moves or loans, the degree of damage caused by pest insects or decay as a result of pyrite-marcasite destabilisation.

Figure 4.7.2.a: Photographing insect drawers at the NMWIN in Winterthur (photo Moritz Lüthi)

Recommendations

- → collect metadata (in lists) of all collections on storage unit level, unless collection is subject to frequent change
- → take photos (and associated metadata) if they add value to the lists
- → publish pictures and lists online, but plan to update pictures if collections undergo change at the unit level (for example, specimens are added or re-determined)

Example

- the Naturhistorisches Museum Bern has imaged around a third of their entomological drawers and added tags to improve accessibility. This will also allow for remote determination of unsorted material by external experts: www.nmbe.ch/en/recherche-et-collections/view-our-collection-from-your-sofa

Further reading

- for information on whole-drawer imaging in entomological collections, see Mantle et al. (2012)

4.7.3 Curatorial unit level

The curatorial unit is normally the smallest 'container' with its own set of data on a label (Woodburn 2019). This can be a mounted fox, a pinned insect, a jar of small fish, a herbarium sheet, a vial (out of many stored together in a jar) containing 10,000 mites, a slide with uncountable microfossils or a sample in a vial with alcohol (see figure 4.7.3.a). A curatorial unit is usually the entity that receives an identifier. Descriptions on the curatorial unit level pertain to information databased from the label but also to information captured from a curatorial unit ('object') such as a picture or a three-dimensional scan.

Databasing

Databasing at the curatorial unit level generates resources of high value for research and society (Greeff and Wagner 2018). For example, metadata, including georeferenced localities or collection dates of specimens, can be used in studies on population dynamics and climate change. Although databasing all available information per specimen would be ideal and maximise potential applications of the data, data entry is costly and priority must be placed on either the quality of data or the quantity of databased units.

Data quality may pertain to the completeness of transcribed label data. For instance, information on collecting methods, microhabitats and host species may all be present on labels associated with a specimen but not considered a priority and thus not databased, despite the importance of such information for particular research questions. Data quality may also apply to the degree of interpretation and enrichment of the data. Location data from a label may only be partially databased, for example, at the level of province or canton, or the contents of the entire label may be databased and subsequently enriched with geo-coordinates. Furthermore, distinguishing between verbatim and interpreted data allows for maximum transparency and is particularly relevant to the transcription of geographic information and dates.

Data quality may also refer to the taxonomic identification of specimens. Curators and collection managers have debated at great length whether specimens need to be determined before digitisation. Usability of data significantly increases if taxonomic identification or, even better, verification of existing identifications are done before databasing. Yet, the publication of specimen data should not be hampered by specialists being unavailable or too costly. Even if taxonomic information is incomplete, wrong or outdated, researchers may still find relevant study material and eventually even revise determinations retroactively. In this regard, automated species identification based on image recognition has the potential to both permanently and dramatically change current practices of databasing and collection management. (Wäldchen and Mäder 2018). Both Naturalis Biodiversity Center and ETH Zürich are currently developing machine learning solutions for taxonomic identification in natural history museums (Schermer et al. 2018, Sunderland and Greeff 2020). To ensure the correct application of data in this context, it is essential to clearly indicate a degree of confidence for taxonomic determinations when publishing specimen data.

Pictures

Taking pictures is a time-consuming process that significantly inflates the need for storage space in databases. Not surprisingly, the purpose of imaging in mass-digitisation has been discussed at length among collection personnel and decision makers. In some natural history databasing projects, imaging became a routine procedure in recent years as data storage costs dropped and digitisation was made easier by automated methods. Particular mention should be made of herbaria, which may be efficiently imaged by conveyor belt-driven digitisation methods generating tens of thousands of scans per day (greatly facilitated by the fact that the label and the object were usually on the same sheet, and that material is usually flattened during the specimen drying process). Nevertheless, capturing images is still much slower in other types of collections

Figure 4.7.3.a: Aquatic insects in the NSFL in Triesen (photo Sven Beham)

and should be carefully planned before being introduced on a large scale.

Images prove particularly valuable in the documentation of label data. Similar to verbatim data, photos and scans represent non-interpreted, original data. Transcription of label information is prone to errors, especially in the case of illegible handwriting, old labels or letters written in unfamiliar alphabets. In such situations, the availability of photos can assist users in the verification and correct interpretation of label data. Apart from data transparency, imaging labels can improve digitisation procedures in several additional ways. In classical databasing, digitisation staff will need to handle the specimen to get access to the label data, and in some cases for certain groups will only have one hand free to operate the keyboard. If transcription is done from images on a computer screen, specimen handling is minimised and typing becomes more efficient. Furthermore, the entire process of label transcription can be outsourced to citizen scientists, workforces in other countries or other remote sources of labour once the labels have been imaged.

Capturing images or even three-dimensional scans to document morphological features, however, is rarely advisable in mass-digitisation. With the exception of herbarium sheets, most collection objects are three-dimensional and require laborious scans or multiple images from different angles to cover the entire surface, thereby increasing storage volumes and expenditure of time. Type specimens may be the only use case for high-resolution imaging, as they are limited in numbers, of high scientific value and should be handled and loaned as little as possible. If specimens are imaged for automated species identifications as mentioned above, low resolution photos should suffice.

Recommendations

- → use Join the Dots to prioritise collections for databasing
- → try to optimise workflows for maximum efficiency as describe in section 4.1.2 on mass digitisation
- → focus on capturing data rather than generating beautiful pictures
- → database associated field books, notebooks and other archive documents, if available, and especially if label data are insufficient
- → take images of labels if possible
- → record verbatim data and add interpretation separately
- → begin databasing collections with reliable taxonomic identifications
- → always indicate the reliability of taxonomic identifications when publishing specimen data
- → use a value of 'unknown' in the case of missing information and a value of 'empty' if information is known but not digitised or unclear

Examples

- the Entomological Collection of ETH Zürich modernised and digitised their holdings of more than 150,000 palearctic Macrolepidoptera. Digitisation included prior verification of all identifications by experts, imaging of all labels, transcription of all label data and subsequent georeferencing (Eastwood 2017)
- databasing on the curatorial unit level pertains to all kinds of specimens: DeWalt (2018) modernised and digitised a wet collection of stoneflies (Plecoptera) and published a nice methods paper about their experience

Further reading

- for information on industrial style data transcription on the collection unit level, see Philipps et al. (2019)
- for information on standardisation of transcribed digital specimen data, see Groom et al. (2019b)
- for specifications on image file formats, see Deutsche Forschungsgemeinschaft (2013)

4.7.4 GBIF Registry of Scientific Collections

The GBIF Registry of Scientific Collections builds on the former Global Registry of Scientific Collections (GRSciColl). It is a clearinghouse of information about the world's scientific institutions, collections and associated staff members. It currently holds information on more than 5000 collections, more than 8000 institutions and 15,000 staff members. Most scientific disciplines are represented, including biology and earth sciences, as well as applied fields like veterinary medicine and agriculture.

The principal objectives of the GBIF registry are twofold. Firstly, access to information about institutions, their scientific collections and staff members should be facilitated, and secondly, the GBIF registry provides machine-readable identifiers and unique codes for institutions and collections, elements used in the Darwin Core standard data exchange format by the biodiversity informatics community. These codes are also used for citations in journals such as ZooKeys. Other registries such as Index Herbariorum, the NCBI Institution table and Collection table, Biorepositories.org or the Biodiversity Collections Index are included in the GBIF registry as well. Currently, a new database schema and new API services are under discussion. The GBIF registry of scientific collections seeks to preserve historical identifiers for institutions and collections and provides resolution services for codes.

Recommendations

- → it is becoming apparent that the GBIF registry will become a central element in the infrastructure of iDigBio and DiSSCo. Therefore, institutions and collections should register here
- → participate in the requirements engineering of the GBIF registry of scientific collections, formerly known as GrSciColl

Examples

- institution and collection codes are mandatory in the Darwin Core standard. Commonly, they are based on the identifier of the GBIF registry
- Index Herbariorum provides information on the world's herbaria (addresses, contacts, specialities, size, etc.): http://sweetgum.nybg.org/science/ih/
- iDigBio Collections provides a list of all natural history collections in the United States of America: www.idigbio.org/portal/collections

Figure 4.7.4.a: Entomological collection at the ZMZ in Zürich (photo Martina Schenkel)

Further reading

- for more information on the creation of a catalogue of the world's natural history collections, see Hobern et al. (2020; hyperlink to https://doi.org/10.35035/p93g-te47) or Smith et al. (2018)

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Notes

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